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Obesity and Dental Caries in Children in Plymouth

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OBESITY AND DENTAL CARIES IN CHILDREN IN PLYMOUTH

by

MARTHA PAISI

A thesis submitted to the Plymouth University
in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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Peninsula School of Medicine and Dentistry

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Abstract

Obesity and Dental Caries in Children in Plymouth

Martha Paisi

Background: Obesity and dental caries are two of the most common conditions affecting children and both have significant implications on children's wellbeing and future health. Even though research into the relationship between the two conditions has been conducted for many years, results to date remain equivocal. Furthermore, the majority of the studies only examined individual-level determinants of the two conditions.

Aim: The current work aimed to examine the nature, direction and effect size of the relationship between obesity and caries in children in Plymouth, United Kingdom. It also aimed to better understand the individual and the broader environmental determinants of the two conditions.

Methods: The study was divided into three parts: a systematic review examining the relationship between the two conditions in children and adolescents using a validated and study design specific tool; an analysis of extant data concerning Plymouth children's weight status and dental caries using a spatial approach; and lastly a school survey of local children aged four to six years, where different types of obesity were examined in relation to dental caries. In the latter survey, several neighbourhood-level and individual characteristics were also examined in relation to the two conditions.

Results: The systematic review indicated that there was no consistent association between high Body Mass Index and caries in individuals less than 18 years old. The ecological study identified spatial clusters of obesity and caries in Plymouth children and the results supported the importance of developing geographically focused

prevention and intervention strategies which take into account the presence of spatial heterogeneity. The school survey did not find evidence of a relationship between any type of obesity and caries in Plymouth children but identified several indicators that affect the distribution of the two conditions.

Conclusions: This work has given insight into the nature, direction and size of the relationship between obesity and caries in Plymouth children and has highlighted several indicators which need to be considered when developing local public health interventions.

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Chapter 1. Introduction

1.1 General introduction to the topic

Obesity and dental caries are important concerns worldwide and are two of the most common conditions affecting children (American Academy of Pediatrics: Committee on Nutrition, 2003; CDC, 2013; FDI World Dental Federation, 2015; Petersen et al., 2005; WHO, 2003b; WHO, 2016b; Yang et al., 2015). Both are multifactorial diseases which can adversely affect a child's physical and psychological wellbeing and are also very costly to the healthcare services (Alm, 2008; Colak et al., 2013; Do & Spencer, 2007; FDI World Dental Federation, 2015; Friedlander et al., 2003; Pulgaron, 2013; Whitaker et al., 1997; WHO, 2000b; WHO, 2003a; WHO, 2016b). In addition, evidence in the literature indicates that there are severe social inequalities in the distribution of both childhood obesity and dental caries, with disadvantaged children or those living in deprived areas being more profoundly affected by the two conditions in terms of both prevalence and severity (Kinra, Nelder & Lewendon, 2000; Locker, 2000; Marshall et al., 2007; Peng et al., 2014a; White, Rehkopf & Mortensen, 2016). Early childhood obesity and caries are also predictive of the corresponding conditions in adulthood (Broadbent et al., 2013; Li & Wang, 2002; Whitaker et al., 1997; WHO, 2016b), thus making it imperative for preventive strategies targeting the two conditions to be implemented at an early stage in life.

Obesity in children has increased more than two-fold in the last three decades (Ogden et al., 2014), giving rise to associated adverse health outcomes and costs (Anderson & Butcher, 2006). With regard to dental caries, levels of the condition still remain high in some countries (Azizi, 2014; Dukić, Delija & Lulić Dukić, 2011; Sacic et al., 2016; Wyne, 2008) and despite a dramatic reduction in the average levels of the condition in

the 1980s in several countries, this trend has reportedly reached a plateau or even reversed in the primary dentition (Australian Research Centre for Population Oral Health: The University of Adelaide: South Australia, 2011; Dye & Thornton-Evans, 2010; Haugejorden & Birkeland, 2002; Lencova, Pikhart & Broukal, 2012; Marthaler, 2004; Speechley & Johnston, 1996). Furthermore, in the United Kingdom (UK), over a period of nine years, there has been a significant increase in the number of children admitted to hospital for tooth extractions due to caries, with most of them being treated under general anesthesia (Moles & Ashley, 2009); the most common age for children undergoing extractions for caries was five years old.

Given the high prevalence of both obesity and caries among youth, the negative health outcomes associated with them, and the fact that they share potentially common aetiological factors, such as diet and lifestyle (Alm, 2008; Spiegel & Palmer, 2012; Marshall et al., 2003) there has been an increasing interest in the association between them. However, primary studies and systematic reviews examining the relationship between childhood/adolescent weight status and caries have yielded inconclusive and conflicting results (Alkarimi et al., 2014; Alswat et al., 2016; Bafti et al., 2015; de Jong-Lenters et al., 2015; Hayden et al., 2013; Hong et al., 2008; Hooley et al., 2012; Kantovitz et al., 2006; Li et al., 2015a; Macek & Mitola, 2006; Peng et al., 2014a; Silva et al., 2013; Yang et al., 2015; Yao et al., 2014). As a result, the nature, direction and effect size of the relationship have not yet been established.

Interestingly, a recent study examining the relationship between increased weight status and caries in 12-year old children, found that general obesity did not relate to caries, however, central and peripheral did (Peng et al., 2014b). This suggests that the nature of the relationship between the two childhood conditions may be affected by the type of

obesity assessed, and the authors concluded that including multiple types and indices of obesity may offer additional insights into the relationship.

Notably also, the great majority of studies in the field only examined individual-level determinants of the two conditions while investigation into how social factors and the environment may affect the distribution of the two conditions are rare. It is indeed increasingly recognised that the place and the conditions in which we live have an impact on health and disease status (Glasgow Centre for Population Health, 2013): The Social Determinants of Health Theory (Commission on Social Determinants of Health, 2008) highlights that social factors and one's living conditions can impact the development of health conditions and the importance of tackling the environmental and structural determinants of chronic conditions has also been pointed out (Watt & Sheiham, 2012).

Thus, in order to understand the problem of overweight/obesity and dental caries, further studies are needed to identify the mechanisms which cause increased prevalence of both conditions in the broader environment. The results of several studies strengthen the hypothesis that it is not only the individual behaviours and lifestyle that have a role in the emerging patterns, but that place itself and particularly the characteristics of the built environment may also have a role (Burgoine et al., 2014; Campos et al., 2011; Do, Ha & Spencer, 2015; Ismail et al., 2009; Lazarou et al., 2008; Penney et al., 2014; Pouliou & Elliott, 2009). However, the use of spatial epidemiology in the study of both conditions is very limited and there is perhaps a need to extend traditional methods of epidemiology (Pouliou & Elliott, 2009).

Taking into consideration all of the above, it appears evident that understanding the link between caries and obesity from an ecological perspective is paramount to the development of appropriate preventive interventions that would target the two

conditions simultaneously. This would also enable a common risk factor approach to be implemented which could improve the overall health of children. A multidisciplinary and combined approach targeting the two conditions at the same time could potentially improve the efficiency, effectiveness and cost implications of future interventions.

Chapter 2. Literature Review

This chapter reviews the literature on obesity and caries, in terms of their definition, epidemiology, aetiology, consequences and methods of assessment. Evidence into the relationship between the two conditions is also presented and discussed in light of the research reported in this PhD thesis.

2.1 Obesity

2.1.1 Definition of obesity

Obesity is generally considered to be residue of body fat accumulated in the adipose tissue, (Lahti-Koskia & Gill, 2004) which can have significant implications on an individual's health (WHO, 2016c). It results from a shift towards positive energy balance when more calories are taken in than expended (WHO, 2016c).

The most widely used method of assessing weight status in both adults and children is Body Mass Index (BMI), which is determined by dividing weight (in kilograms) by height (in meters) squared (WHO, 2016c).:

$$[\text{BMI} = \text{weight (kg)} / \text{height (m)}^2]$$

In adults, a BMI of 25 kg/m² to 29.9 kg/m² is commonly used to define overweight while a BMI of 30kg/m² or above indicates obesity (WHO, 2016c). However, classification of BMI measurements in children and adolescents is not as simple (Flegal, 1993) and it is suggested that BMI should be interpreted using reference growth standards (Scottish Intercollegiate Guidelines Network, 2010a). Further details into the reasons that BMI classification is more complex in children and how it is applied, as well as other methods of assessing an individual's weight status will be provided later in the thesis.

2.1.2 Obesity epidemiology

The prevalence and trends in obesity at international, national and local levels are presented below along with a description of the prevailing population inequalities in obesity.

2.1.2.1 Childhood Obesity worldwide-Prevalence and trends

Obesity has been characterised as a significant public health problem and has increased substantially in recent years (Reilly, 2005; WHO, 2016b). In children, it has increased more than twofold in the last three decades, while in adolescents it has quadrupled. In the US, the country which is considered to have the highest prevalence of childhood obesity worldwide, the percentage of children who are obese and are aged 6 to 11 years, rose from 7% in 1980 to almost 18% in 2012 (Ogden et al., 2014). Over the same period, there was a similar increase (16%) in the prevalence of the condition among US adolescents. In 2011-2012, almost 17% of children and adolescents in the US between the ages of 2 and 19 years were obese (Ogden et al., 2014). Recent data also show that obesity has significantly increase in the US youth between 1999 to 2000 and 2013 to 2014 (Ogden et al., 2015).

Although the greatest increases in obesity prevalence among children have been observed in developed countries, evidence shows that the childhood obesity is high in other regions as well (James, 2004). The Global Burden of Disease study 2013 indicated that since 1980 the prevalence of overweight/obesity in young people has risen both in developed and developing nations (Ng et al., 2014). More specifically, in 2013 23.8% and 22.6% of boys and girls respectively in developed countries were either overweight or obese, while in developing countries 8.1% to 12.9% of boys and 8.4% to 13.4% of girls were either overweight or obese (Ng et al., 2014).

2.1.2.2 UK prevalence and trends

In the UK, obesity in children started to increase in the 1980s and the UK is now considered to have one of the highest prevalence of childhood obesity in the European Union. Data collated by the International Association for the Study of Obesity showed that 22% of boys and 26% of girls in England are overweight, as compared to 23% of boys and 21% of girls who are considered to be overweight in the countries that belong to the Organisation for Economic Co-operation and Development (OECD) (OECD, 2014).

The Health Survey for England, which has taken place on a yearly basis since 1991 measures amongst other things, the weight and height of children in private households in England. It has shown that in 2013, the obesity prevalence in boys and girls aged 2 to 15 years was 16% and 15%, respectively (The Health and Social Care Information Centre, 2014). The combined prevalence of overweight/obesity was 30% and 29% for the boys and girls, respectively (The Health and Social Care Information Centre, 2014). The data also indicated that the proportion of obese children increased with age, ranging from 9% among girls and boys aged two to seven years, to 17% of boys and 22% of girls aged 13 to 15 years (The Health and Social Care Information Centre, 2014). Lower figures were observed in the latest Health Survey for England, where in 2014, 17% of children from 2 to 15 years were found to be obese and 14% were overweight (The Health and Social Care Information Centre, 2015).

Regarding trends in obesity and overweight between 1995 and 2013, it was found that there was an increase in obesity, as 11% and 12% of boys and girls, respectively, aged 2 to 15 years were classed as obese in 1995 and 16% and 15% respectively, were obese in 2013. There was also a steady increase in obesity between 1995 and 2004 when obesity reached its highest level (The Health and Social Care Information Centre, 2014).

The National Child Measurement Programme in England is a UK government initiative which began in 2005 and involves the annual measurement of height and weight of children aged four to five years (Reception year) and those aged 10 to 11 years (Year 6) at mainstream schools in England (The Health and Social Care Information Centre, 2014). The results of this program for the year 2013/14, showed that 14.4% of the children aged 10 to 11 years were overweight and another 19.1% were obese (The Health and Social Care Information Centre, 2014). Thus, around a third (33.5%) of children in this age category were overweight/obese, which was similar to the situation in 2012/13 (33.3%) and slightly higher than in 2006/07 (31.6%). In four to five year olds (Reception year), 9.5% were found to be obese and 13.1% as overweight in the academic year 2013/14. Therefore, in this age category 22.5% of children were estimated to be overweight or obese (The Health and Social Care Information Centre, 2014). The latest results of the NCMP 2014/15 (The Health and Social Care Information Centre, 2015) indicated that the prevalence of overweight/obese children in both years were slightly lower than in 2013/14; in Reception year, 21.9% of the children that took part had excess weight (overweight/obese) compared to 22.5% in 2013/14, and in Year Six more than third (33.2%) of the participants were overweight or obese (compared to 33.5% in 2013/14) (The Health and Social Care Information Centre, 2015).

The results of the 2013/14 NCMP survey also indicated that there were clear social inequalities in childhood obesity prevalence in both age groups. In children in Year 6, obesity prevalence was 24.7% among children studying in schools located in the most deprived decile, as compared to 13.1% among children in schools found in the least deprived areas. The corresponding values for children in the Reception year were 12% and 6.6%, respectively (The Health and Social Care Information Centre, 2014). Similarly, the findings of the NCMP 2014/15 showed that the prevalence of obesity

among children living in the most deprived areas was twice that of those who lived in the least deprived areas. Furthermore, in the Health Survey for England lower socioeconomic status (SES) was associated with a higher burden of the condition, with higher number of overweight/obese children found in lower income quintiles (The Health and Social Care Information Centre, 2015).

2.1.2.3 Childhood obesity in Plymouth-Prevalence and trends

With regard to overweight/obesity rates in the local context, results from the NCMP which achieved a participation rate of 92.8%, indicated that in 2013/14, 15.2% of Plymouth's four to five year olds were overweight and 9.8% were obese. The prevalence of healthy weight children was found to be below the national average (74.5% as compared to 76.5%) and the prevalence of obese children (9.8%) was above the national average of 9.5% (The Health and Social Care Information Centre, 2014). Furthermore, obesity rose from 8.6% in 2006/07 to 9.8% in 2013/14 (The Health and Social Care Information Centre, 2008;The Health and Social Care Information Centre, 2014).

With regard to health inequalities, in 2013/14 obesity in four to five year old children was 5.5 percentage points higher in the most deprived group of neighbourhoods (11.9%) than in the least deprived ones (6.4%) (Public Health: Office of the Director of Public Health: Plymouth City Council, 2015b); the inequality gap for obesity increased from 3.5% in 2006/07 to 5% between the least and most deprived areas in 2013/14.

Results of the latest local NCMP 2014/2015 indicated that while obesity in children aged 10 to 11 years was below the national average (17.9% as compared to 19.1%), 9.7% of children aged four to five years were obese as compared to the national average of 9.1% (Public Health: Office of the Director of Public Health: Plymouth City Council, 2016). There was a difference between neighbourhoods of different deprivation status

and the inequalities gap increased for both age groups between 2007/08 to 2014/15 (from 1.4% in 2007/08 to 3% in 2014/15 for children 4-6 years and from 6.7% in 2007/08 to 8.1% in 2014/15).

2.1.3 Obesity aetiology

Obesity is multifactorial and complex and is considered to result when various genetic, behavioural, environmental, physiological, social and cultural factors interact (Biro & Wien, 2010; Keller, 2008; Racette, Deusinger & Deusinger, 2003).

The term ‘obesogenic environment’ highlights the fact that obesity should not simply be viewed as being caused by changes in eating and physical activity patterns, but rather as the outcome of changes in the society and the environment we live in and which promote unhealthy weight gain. Swinburn, Egger and Raza (1999, p.564) have defined the term obesogenic as ‘the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals or populations.’ Thus, the cause of obesity is multifactorial and as such, it should not be examined solely in relation to lifestyle and behaviour. Recently, a systematic review of narrative and systematic reviews published between 1990 and 2014 concluded that the main cause of the obesity increase in children still remains unclear (Ross, Flynn and Pate 2016).

2.1.3.1 Behavioural risk factors

The energy balance equation determining weight status can be affected when the energy intake exceeds energy utilisation. The impact of environment on overweight and obesity is believed to be mediated primarily through dietary and physical activity behaviours, both of which are considered to be modifiable aspects of the equation (Troiano & Flegal, 1998). These key modifiable factors are considered to have had a pivotal role in the alarming rise overweight and obesity in the last decades [(Office of the Surgeon General (US), 2010)].

2.1.3.1.1 Dietary risk factors

A dietary factor that has been linked to overweight and obesity is the increased intake of energy-dense foods, which include foods and beverages that have high sugar and fat content (World Obesity Federation, 2015). This association appears in both child and adult populations.

2.1.3.1.1.1 Beverages high in sugar

In a recent systematic analysis of data from cohort studies and randomised controlled trials (RCTs), the WHO highlighted that sugar intake can significantly affect body weight (Te Morenga, Mallard & Mann, 2013). In this review, analysis of results from 30 RCTs indicated that lower sugar intake was associated with a significant reduction in weight (0.80 kg, 95% CI: 0.39, 1.21; $p < 0.001$), while increased consumption of sugar resulted in a similar rise in body weight (0.75 kg, 95% CI: 0.30, 1.19; $p = 0.001$). Other systematic reviews (Bucher Della Torre et al., 2016; Trumbo & Rivers, 2014), as well as a review of systematic reviews and meta-analyses (Keller & Bucher Della Torre, 2015), confirmed that most of the evidence in the field indicates that a positive relationship exists between intake of sugar-sweetened beverages (SSB) and increased weight status in children and adolescents. However, the latter authors, similarly to Bucher Della Torre et al. (2016) noted that recent evidence from high quality meta-analyses is not consistent and they emphasised the need to improve methodological aspects of primary studies and reviews.

With regard to the relationship between sugar intake and obesity in adults, a prospective cohort study which examined the relationship between SSB and weight change as well as risk of type 2 diabetes mellitus in US female nurses ($N = 91,249$ at baseline), indicated that greater weight gain was evident in those with a higher intake of SSB. More specifically, over a four-year period and after adjusting for confounders, women who

increased their beverage consumption from one or fewer weekly, to one or more per day, had the highest weight gain. In contrast, those who decreased their beverage consumption had the smallest gain in their weight (Schulze et al., 2004).

In children, a strong and significant association between intake between SSB and obesity risk has been demonstrated in several longitudinal and case-control studies (Martin-Calvo et al., 2014; Mirmiran et al., 2015) and the main dietary factor believed to be responsible for the development of obesity in children is the consumption of SSB (James & Kerr, 2005; Moreno & Rodríguez, 2007). In the US, a concomitant rise in the per capita consumption of soft drinks and obesity prevalence among children has been observed and a prospective analysis in an ethnically diverse sample of 548 children with a mean age of 11.7 years, revealed that increased intake of SSB positively related to obesity risk (Ludwig, Peterson & Gortmaker, 2001). In this analysis, for each additional can or glass of SSB that children had on a daily basis, the risk of obesity increased by 1.6 times and the relationship remained significant even after adjusting for confounders (Ludwig, Peterson & Gortmaker, 2001). The analysis also indicated that SSB intake at baseline and changes in consumption of SSBs were predictive of changes in BMI.

The relationship between consumption of SSB and increased weight status was also confirmed in a study of 4,164 children that took part in the Longitudinal Study of Australian Children (Millar et al., 2014) where BMI was associated with SSB consumption both at baseline and at follow up. A very recent study also showed that in 227 children from Mexico aged 8 to 14 years, high consumption of SSBs significantly increased the risk of obesity (Cantoral et al., 2016). Although early introduction of SSBs did not affect the risk of obesity, children with the highest consumption of SSBs were three times more likely to suffer from obesity as determined by BMI (OR=2.99,

95% CI: 1.27, 7.00) or waist circumference (OR=2.70, 95% CI: 1.03, 7.03) (Cantoral et al., 2016).

The findings above were consistent with those of a systematic review (Malik, Schulze & Hu, 2006) which investigated the relationship between SSB consumption and weight gain. Based on the results of high-quality prospective studies and feeding trials, the review concluded that there was strong evidence that SSBs contribute to weight gain, and consequently obesity, in children and adolescents. This effect was independent from other factors (Malik, Schulze & Hu, 2006). In the previously mentioned systematic review commissioned by WHO (Te Morenga, Mallard & Mann, 2013), it was shown that children who had the highest sugar intake were 1.55 more likely to be overweight or obese against those who had the lowest intake.

Overall, despite the fact that the significant rise in obesity is likely to be of multifactorial aetiology, in terms of dietary behaviours, the increased consumption of sweetened beverages and soft-drinks in particular, is likely to be an important contributory factor (Ludwig, Peterson & Gortmaker, 2001; Moreno & Rodríguez, 2007; Te Morenga, Mallard & Mann, 2013). Yet, soft drinks constitute one of the main sources of added sugars in children's diets (Block, 2004; Keller & Bucher Della Torre, 2015) and evidence indicates that the consumption of SSB has increased in parallel with increasing trends of overweight and obesity (Hu, 2013). It appears that SSB may contribute to weight gain through an increase in the total intake of energy (Malik, Schulze & Hu, 2006; Mates, 1996). The biological mechanism linking sweetened drinks and obesity is that after consuming energy in the form of a liquid, individuals do not feel as full as when the energy is consumed in the form of solid food and therefore do not reduce their subsequent food intake (Ludwig, Peterson & Gortmaker, 2001). This is because of low satiety offered by liquids (Malik, Schulze & Hu, 2006; Mates, 1996).

2.1.3.1.1.2 Foods with high fat content

High energy diets which include foods with high fat content have also been cited as an important factor that have led to the rise in obesity.

With regard to the relationship between obesity and the intake of foods high in fat, the Avon Longitudinal Study of Parents and Children showed that in 521 children aged five and nine years and in 682 children aged seven and nine years of age, a diet high in energy and fat and low in fibre related to increased body fat and risk of obesity (Johnson et al., 2008). In addition, a review of publications from the same study showed that energy-dense diets increased body fat from mid-childhood up to adolescence (Emmett & Jones, 2015).

On the other hand, a study which examined the association of childhood obesity with high fat foods and low physical activity in 8 to 10 year old children, showed that neither factor was an independent risk factor for obesity; the authors suggested that the two factors may act synergistically when both are present in the same individual (Muecke et al., 1992). Similarly the longitudinal European youth heart study which included 384 children aged nine years old, did not find evidence that fat intake related to weight change over a six-year period (Brixval, Andersen & Heitmann, 2009). Despite the popular belief that consumption of fat has led to the rise in obesity rates in the last decades, there have been reports that dietary fat intake during this period has actually declined (Ahmad, Ahmad & Ahmad, 2010).

2.1.3.1.1.3 Low-Energy Foods

Reduced consumption of low-energy foods, including fruit and vegetables, is another dietary factor that has been linked to the obesity epidemic (Tohill et al., 2004; World Obesity Federation, 2015). The protective effect of fruit and vegetables against obesity is believed to be moderated through their high water and fibre content, which could

decrease energy density, promote satiety and as a result reduce energy intake (Rolls, Ello-Martin & Tohill, 2004).

In a prospective cohort study with a 12-year follow-up which included 74,063 female nurses aged between 38 to 63 years, it was shown that by increasing consumption of fruit and vegetables, obesity risk and weight gain could be reduced (He et al., 2004). In a further study of 325 children aged between 3.8 to 7.8 years, a significant association between low fat mass and a diet that had high intake of vegetables was found and this association remained significant even after adjusting for confounders (Wosje et al., 2010). In contrast, a prospective cohort study of children and adolescents between 9 and 14 years of age (8,203 girls and 6,715 boys), weight status inversely related to vegetable intake only in boys and this relationship did not remain significant after adjusting for total energy intake (Field et al., 2003).

However, a systematic review which examined the association of fruit and vegetables with obesity (Ledoux, Hingle & Baranowski, 2011) found a weak inverse relationship between fruit and vegetable intake and obesity among overweight adults, while the relationship appeared to be unclear in children. The authors reported that it could not yet be established whether an increase in fruit and vegetable consumption would result in a decline or slower increase in obesity unless calorie intake was lowered or physical activity increased.

2.1.3.1.2 Reduced Physical activity-Sedentary Lifestyle

Other behavioural factors which have been associated with the rising levels of obesity are associated with reduced energy expenditure. These include reduced physical activity levels and increased levels of sedentary lifestyle (World Obesity Federation, 2015).

2.1.3.1.2.1 Reduced physical activity levels

The UK physical activity guidelines 2011, endorse an hour at least of moderate to vigorous physical activity for individuals aged 5 to 18 years; it is also recommended that children aged under five years who can walk, should have a least 180 minutes (three hours) of physical activity daily, spread throughout the day (Department of Health, 2011b).

The Health Survey for England showed that in 2008 only 28% of English boys and 19% of girls aged 5 to 15 years met the recommendations for physical activity; the figures further decreased in 2012 when only 21% of boys and 16% of girls met the guidelines (The Health and Social Care Information Centre, 2014). Low levels of physical activity were also related to deprivation, with children living in low income houses reportedly being less active (The Health and Social Care Information Centre, 2014). The recommended levels of physical activity are also currently not being met by adults or children in other countries. For example, in 2012 only one in five European children reported that they took part in regular moderate to vigorous intensity exercise (OECD, 2012).

Several studies have shown that physical activity levels in children are inversely related to obesity. For example, Hanley et al. (2000) showed that among children and adolescents aged 10 to 19 years, in those in the third and fourth quartile of fitness, the risk of obesity was significantly lower than in their counterparts in the first quartile of fitness. Moreover, overweight children and adolescents were found to have lower activity levels when compared to their healthy weight peers (Bernard et al., 1995). More recent evidence from a National Health Behaviour study in the Czech Republic, which included a representative sample of 19,940 adolescents aged 10.5 to 16.5 years old, showed that increases in overweight/obesity between 2002 to 2014 in both boys and

girls were concomitant with decreases in physical activity (Sigmund et al., 2015). In addition, a cross sectional study which included 746 children aged six to nine years also provided evidence that low physical activity positively related to obesity as measured by BMI and waist circumference. Low levels of physical activity increased the likelihood of general and central obesity by 13% and 18%, respectively (Abril et al., 2013).

Increased levels of physical activity protect against obesity by maintaining the energy balance and preventing the accumulation of fat in adipose tissue (Schonfeld-Warden & Warden, 1997). Except for the resulting increase in energy expenditure and therefore a negative energy balance in the equation, physical activity also has beneficial effects on the obesity associated (FTO) gene. FTO is one of the genes that are known to contribute to polygenic obesity (Hess & Brüning, 2014). In a meta-analysis that used data from studies in adults (n=218,166) and nine studies of children (n=19,268), physical activity was found to attenuate by 27% the association of this gene to obesity in physically active adults. This was not evident in children or adolescents (Kilpelainen et al., 2011).

Overall, it has been suggested that any efforts that include physical activity are likely to assist efforts in tackling obesity in children (Hewitt-Taylor, Alexander & McBride, 2004). However, clear evidence about the frequency and intensity of activity needed to affect body composition and health is limited.

2.1.3.1.2.2 Sedentary lifestyle

Sedentary lifestyle, and in particular television viewing, is another behavioural factor that is believed to be implicated in the rise of obesity (Rey-Lopez et al., 2008). The evidence actually suggests that sedentary lifestyle may be more important than physical activity with regard to obesity (Lazarou & Soteriades, 2010).

The American Academy of Pediatrics advises that in children younger than two years of age, television viewing should be discouraged, while for those aged two years and above total media time should be no more than one to two hours a day (American Academy of Pediatrics: Committee on Public Education, 2001). In the UK, it is recommended that in all children aged under five years the amount of time being restrained or sitting should be kept to minimum, while those aged 5 to 18 years should minimise the amount of time that they are sedentary. However, no sufficient evidence exists to quantify this precisely in terms of a time limit for sedentary behaviour (Department of Health, 2011b).

Despite discrepancies between the guidelines of different countries, the figures for the time children spend watching TV, or engaging in other sedentary activities show that 26.5% to 49.2% of EU children aged 11 to 15 years watch TV for four hours or more per day (Currie et al., 2004; Swinburn & Shelly, 2008). Canadian and American children are reportedly spending 7.8 hours and 7.5 hours/day, respectively, watching TV (Campbell, Crawford & Ball, 2006; Leatherdale & Ahmed, 2011).

The link between TV viewing and the risk of obesity was first pointed out by Dietz and Gortmaker (1985), who analysed data from three samples of the National Health and Examination Survey (NHANES). NHANES is a large representative survey in the US which is used to assess the overall health of the population (CDC, 2017). The analysis showed that for every additional hour of television viewing, obesity prevalence in adolescents aged 12 to 17 years increased by 2% and the authors suggested that TV viewing may cause obesity in some young people (Dietz and Gortmaker, 1985).

Indeed, the number of hours spent watching TV is considered an important element when examining possible causes of obesity. In 1,468 German children between five and seven years old, overweight was associated with sedentary lifestyle, unhealthy eating

patterns and low social status (Muller et al., 1999). Importantly, it was shown that, TV viewing of more than one hour daily related to increased intake of energy-dense foods, such as sweets and pizza. In contrast, healthy food items such as fruit and vegetables were not commonly eaten while watching TV (Muller et al., 1999). Comparable results were found in Cyprus, Canada and the US, where television viewing of four or more hours per day, significantly increased the risk of obesity in children and/or adolescents (Andersen et al., 1998; Hanley et al., 2000; Lazarou & Soteriades, 2010).

A study in Australia (Wake, Hesketh & Waters, 2003) which included 2,862 children aged 5 to 13 years showed that there was a significant relationship between television viewing and children's BMI. However, after adjusting for parents' BMI and education, number of brothers and sisters, food consumption and activity levels, TV viewing was no longer independently related to child BMI, which means that any of these variables may influence the way in which TV viewing is related to increased body weight (Wake, Hesketh & Waters, 2003).

The mechanism by which sedentary lifestyle, such as TV viewing and playing computer games, increase childhood obesity risk is believed to be mediated primarily through the acquisition of unhealthy behavioural patterns related to eating and physical activity. Increased daily energy intake, increased frequency of meals and between meal snacking frequency, along with increased consumption of high-caloric foods and beverages (which are also commonly the ones that are highly advertised) and the limited consumption of healthy food choices such as fruit and vegetables are unhealthy eating patterns that tend to be associated with TV viewing (Lipsky & Iannotti, 2012; Olafsdottir et al., 2014; Stroebele & de Castro, 2004).

Apart from the cluster of unhealthy eating patterns associated with TV viewing, the reduction in physical activity and energy expenditure is another plausible mechanism by

which TV viewing is associated with increased weight in children (Boynton-Jarrett et al., 2003). Interestingly, a review into the impact of sedentary lifestyle on obesity risk in children and adolescents showed that video games and computers do not pose as much risk as watching TV (Rey-Lopez et al., 2008). This review concluded that there was enough evidence to warrant calling for a reduction in the amount of time spent watching TV, particularly for younger children.

Overall, taking into account additional evidence which shows that obesity is mediating the relationship of TV viewing with metabolic-risk factors (Ekelund et al., 2006), reducing the time that children spend on TV viewing and other sedentary activities, offers potential for tackling obesity in children. This was evident in a RCT which examined the impact of reducing TV viewing, and other sedentary activities on obesity, activity levels and energy intake through an 18-lesson, 6-month classroom curriculum (Robinson, 1999). In their randomised controlled outcome study which included 90 families with obese children aged 8 to 12 years, Epstein et al. (2000), also indicated that promoting reduced sedentary behaviours or increasing physical activity, had beneficial impacts on overweight, body fatness and aerobic fitness.

Despite significant evidence indicating a link between physical activity/inactivity and obesity, disagreements do exist regarding the nature of the association between inactivity and obesity. For example, a longitudinal study which examined 202 children 7 to 10 years of age, showed that it is increased weight status that actually leads to inactivity and not vice versa (Metcalf et al., 2011). This was based on results showing that percentage of body fat was a predictor of changes in physical activity over the three year follow up, while physical activity levels did not predict subsequent changes in percentage body fat over the same period. The authors supported that the inverse nature of this causal association may account for the failure of many physical activity

interventions in preventing development of obesity. Another longitudinal study in children aged 8 to 11 years old, also gives support to this finding as fatness at baseline decreased physical activity and increased sedentary lifestyle after 200 days, but not vice versa (Hjorth et al., 2014). These arguments find support in a systematic review (Metcalf, Henley & Wilkin, 2012) which showed that physical activity interventions did not have a significant impact on activity levels of children. This gives a possible explanation as to why such interventions have been largely ineffective in reducing body fatness in children.

However, the findings in the field are not consistent and another systematic review found that physical activity in children and adolescents brought about significant health benefits (Janssen & Leblanc, 2010), including reductions in obesity. Taking into account the positive impact of physical activity on metabolic health shown in many studies (Blucher et al., 2014; Calcaterra et al., 2013), further research using RCTs is needed to explore the nature of causality between physical activity and obesity in children. The absence of an association between activity and obesity in some studies may simply indicate that activity on its own may not be the best measure of preventing or treating obesity in children, and/or that the impact of activity is affected by other factors (e.g. setting, type and intensity of activity, population etc).

2.1.3.2 Environmental determinants

Even though diet and physical activity patterns are considered to be the key aspects of the energy balance equation, the impact of changes in the social and broader environment which result in the adoption of the unhealthy lifestyle behaviours, must not be overlooked. Such changes include among others, health care, marketing, transportation, education and food processing (WHO, 2016c).

For example, technological advances and industrialisation have led people to acquire more sedentary lifestyles (i.e. preference for computer games and television instead of recreational activities) while safety concerns in different areas means that people, particularly children, may not choose walking as a mode of transportation but instead opt for alternatives which are perceived as safer (CDC, 2015). Intense food and drink marketing targeting children, and increased energy density of the food eaten, have also been implicated in the increase of energy consumption and/or decrease in energy expenditure (Swinburn et al., 2004).

Other environmental factors that have been found to relate to obesity (through their impact on dietary and physical activity patterns) include increases in portion sizes and reduction in cost of many packed snacks and meals, thereby promoting higher caloric intake (McConahy et al., 2004). The greater availability of food high in fat and sugar and SSBs (CDC, 2015), changes to the workplace environment which have resulted in less active occupations, as well as the limited access to healthy foods (Larson, Story & Nelson, 2009) have all been cited as possible factors in the obesity epidemic. Furthermore, changes in the appearance and flavour of processed foods through intense marketing have made it more appealing to the public who therefore become more prone to overeating and increased consumption of energy (Racette, Deusinger & Deusinger, 2003).

2.1.3.3 Structural determinants

Changes in the lived in and built environment have also been connected to the rise of obesity, again through their impact on dietary and physical activity habits.

In a review of the literature which included 33 quantitative studies, children's physical activity levels were higher when there was a better access to 'recreational infrastructure' (e.g. play areas) and 'transport infrastructure' (e.g. existence of pavements) (Davison &

Lawson, 2006). On the other hand, where crime, deprivation and traffic density were high or where there were road hazards, children's levels of physical activity were low (Davison & Lawson, 2006). Aarts et al. (2013) also suggested that changes in the physical environment and the layout of many communities have reduced the space where children can be physically active.

In a recent study examining neighbourhood variables in relation to childhood overweight and obesity in Berlin, Germany, the density of fast food restaurants was found to be a possible influencing factor. Other environmental and spatial characteristics such as walkability, parks, playgrounds, public transport access points were however not found to significantly affect overweight and obesity (Lakes & Burkart, 2016). Although not directly related to BMI, in a sample of 580 children 9 to 11 years old, access to school playground equipment was shown to be inversely associated with sedentary lifestyle (Gomes et al., 2015). In contrast, access to fast-food restaurants located near school premises was positively associated with sedentary lifestyle (Gomes et al., 2015). The impact of built environment on obesity prevalence in children was also identified in a national cross-sectional of 1,140 children in Cyprus where 'geographical characteristics of the place of residence' and 'urbanisation index' were important predictors of obesity (Lazarou et al., 2008). In the UK, several studies have found a link between increased weight in children and density of unhealthy food outlets (Cetateanu & Jones, 2014; Jennings et al., 2011).

Thus, despite the limited number of studies of environmental effects on obesity, it is evident that there is a need for more research to explore the impact of the lived environment on the known, and unknown determinants, of overweight and obesity (Penney et al., 2014).

2.1.3.4 Demographic factors

Several demographic factors have also been linked to the prevalence of overweight/obesity including age, gender, ethnicity and SES.

2.1.3.4.1 SES

Obesity disproportionally affects children (Wang & Beydoun, 2007) with children from low socioeconomic households or who live in more deprived areas being at greater risk than their more affluent peers.

A significant negative association between social index and child overweight and obesity was illustrated in a study that used data from a survey of 28,159 five to six year old German children (Lakes & Burkart, 2016). In the UK, in an ecological study which used data from England's NCMP, area deprivation was shown to be strongly related to obesity rates among school aged children aged four to five years and 10 years (Conrad & Capewell, 2012). Another cross-sectional study which included 2,341 children with mean ages 9 and 12 years, showed that children from the lowest quartile of SES were 1.79 times (CI: 1.35, 2.36) more likely to be overweight or obese than their peers from the highest quartile (Achat & Stubbs, 2014).

Earlier, Wang and Zhang (2006) had examined secular trends in the relationship between SES and overweight, using data from NHANES for 30,417 US children and adolescents between 2 to 18 years of age. The data, which referred to the time period between 1971 and 2002, indicated that there were complex interactions between SES and overweight, as not all low-SES groups were at increased risk of being overweight. The authors identified that several racial, sex and age variables affect the relationship between SES and obesity. The association between obesity and socioeconomic status in US youth was also confirmed as not being consistent across different race and ethnicity groups in another analysis of NHANES data between 2005 to 2008 (Ogden et al., 2010).

A later systematic review showed however, that an inverse relationship did exist between socioeconomic position (SEP) and overweight and obesity in children aged from birth to 15 years of age (Wu et al., 2015). Quantitative analysis of the findings indicated that the risk of overweight or obesity was higher in children with the lowest SEP (OR=1.10, 95% CI: 1.03-1.17) compared to those who were the most affluent (OR=0.41, 95% CI: 1.29-1.55). Interestingly, the inverse relationship between SEP and increased weight status was only evident in developed countries.

Indeed, it appears that the relationship between SES and unhealthy weight is affected by the level of development of the country, as the nature of the association between increased weight status and SES varies by country. In contrast to developed countries, in developing countries low SES children are less likely to suffer from excess weight compared to their affluent peers (Fruhstorfer et al., 2016; Wang & Lim, 2012). This trend is probably explained by food availability. Evidence also suggests that disadvantaged children in developed countries are at increased risk of thinness as well as obesity. This was evident from the secondary analyses of data from the NCMP and the UK Millennium Cohort Study on 2,620,422 and 16,715 children, respectively (Pearce, Rougeaux & Law, 2015).

Despite the complexity in the purported associations between obesity and SES, some plausible mechanisms by which disadvantaged children are at greater risk include the unhealthy infant feeding styles among children from lower SES groups and the fact that these children are more likely to have obese mothers (and maternal obesity influences risk of obesity in the offspring) (Gibbs & Forste, 2014; Reilly et al., 2005). Furthermore, evidence shows that disadvantaged individuals often opt to purchase cheaper foods and these are more likely to be high in fat and sugar (Darmon et al., 2014; Epstein et al., 2007) than more expensive foods.

2.1.3.4.2 Ethnicity

Although obesity in children is increasing among all ethnic and racial groups, its prevalence appears to be higher in non-white populations (Caprio et al., 2008) and ethnicity has been shown to be independently related to increased weight status in children (Achat & Stubbs, 2014).

Analysis of data from the California Health Interview Survey 2003 indicated that the risk of being overweight was higher among adolescents who were American Indians/Pacific Islanders/others than those who were Hispanics, blacks, whites and Asians (Ahn, Juon & Gittelsohn, 2008). In a Northern California obesity intervention study, Ford et al. (2016) showed that severe obesity as well as obesogenic behaviours varied by ethnicity/race with obesity being more common among black people and Hispanics. Analysis of data from 40,921 children and adolescents living in Central Europe also found ethnic differences in morbidities associated with obesity, with Turkish overweight/obese children/adolescents having higher prevalence of hypertension than their Central European peers (Martin et al., 2015).

An earlier systematic review which examined, among others, disparities in obesity between genders, ages, and racial/ethnic groups in the US, showed that minority groups were disproportionately affected in all age groups (Wang & Beydoun, 2007). More specifically, in children and adolescents, the prevalence of obesity was lowest in Non-Hispanic White individuals compared with their peers of non-Hispanic Black and Mexican-American background. The authors concluded that the associations between obesity and the above mentioned parameters are complex. It appears therefore that children from certain ethnic groups are more likely to have obesogenic behaviours than their white counterparts (Falconer et al., 2014).

2.1.3.4.3 Age

Evidence indicates that obesity is more prevalent among older children. Trend data from NHANES II in the US, showed that between 1976-1980 and 2003-2004, the average rate of obesity increase was slower for young children compared to children aged above two years and adolescents (Wang & Beydoun, 2007). A cohort study in the UK (van Jaarsveld & Gulliford, 2015), which analysed primary care electronic health records on 370,544 children between 1994 to 2013 (aged 2-10 and 11-15 years), showed that from 1994 to 2003, the prevalence increased for both age groups, however, between 2004 to 2013 the rates stabilised in 2 to 10 year olds but continued to increase in older children (11-15 years). Furthermore, results from the latest National Child Measurement Program 2014/15) in the UK showed that prevalence of both overweight and obesity were higher among older children (Lifestyles Statistics Team: Health and Social Care Information Centre, 2015). More specifically, 14.2% and 19.1% of children between 10 to 11 years were overweight and obese, while the corresponding figures in children 4 to 5 years old were 9.1% and 12%, respectively.

With regard to the increased prevalence of obesity in older children, some of the factors affecting the condition, particularly the behavioural ones, may have changed over time. For example, a study which included 401 children aged 8 to 13 years (194 boys and 207 girls) indicated that as age increased, levels of physical activity decreased in both genders (Sherar et al., 2007). Malina (1990) suggested that the reduction of physical activity observed in adolescents could be due to the social demands of adolescent life, changing priorities and transition into college/university life. Several other factors (e.g. dietary habits) may also contribute to the observed age differences in obesity prevalence.

2.1.3.4.4 Gender

Although it has been shown that in most countries there is a clear gender difference in obesity prevalence (Ahmad, Ahmad & Ahmad, 2010), it appears that there is no consistent difference between the two genders. In Spain, for example, when trends for overweight prevalence in children and adolescents between 1985 and 1995 were examined, the risk of developing overweight was higher in females compared to males (Moreno et al., 2004). However, analyses of data from the US over a 12-year period showed that that obesity in children and adolescents was more common in males (19% versus 15% in females) and over this time period obesity increased only in males [(males: OR=1.05; 95% CI: 1.01, 1.10) (females: OR=1.02; 95% CI: 0.98, 1.07)] (Ogden et al., 2012).

A review of the literature showed that gender differences in obesity prevalence are generally small (Sweeting, 2008). The same review showed that there is no evidence suggesting that obesity is predominantly found in males or females either in different age groups or according to the definition of obesity used (Sweeting, 2008). Nevertheless, the authors suggested that there were gender differences in both the exposure, vulnerability to obesogenic environments and differences in the consequences associated with obesity and the responses to interventions.

2.1.3.5 Genetics

The role of genes in obesity has been examined in several twin and adoption studies conducted in the 1980s. In 540 adult adoptees in Denmark, a strong relationship between their BMI status and that of their biological parents was found, however this was not the case when their weight status was examined against that of their adoptive parents. The same study found that the relationship between the weight classification of the adoptees and their biological parents was not restricted only to the obese category

but was evident in the whole BMI spectrum. The authors concluded that obesity in adults is influenced primarily by genetic rather than familial factors (Stunkard et al., 1986).

Another study which examined a possible genetic influence on obesity in monozygotic (N=1,974) and dizygotic twins (N=2,097) identified a high heritability for weight, height and BMI in the follow up examinations; these indices significantly correlated over time and a major part of this covariation was found to be genetic, reinforcing the findings of the previous study showing that human obesity is greatly influenced by genetic factors (Stunkard, Foch & Hrubec, 1986). A summary of a number of intervention studies in human identical twins (Bouchard & Tremblay, 1997) showed that there are individuals who are susceptible to gaining weight or who find it more difficult to achieve a reduction in their weight, and genetic factors are believed to be responsible for these differences.

Another study in identical twins which examined differences in their response to prolonged overfeeding (Bouchard et al., 1990) found that there were significant similarities within pairs with regard to changes in fat distribution. The study also showed that during the overfeeding period, changes in weight and body composition differed significantly between, rather than within, the pairs. The authors concluded that the differences among the pairs and the within-pair similarities could be attributed to genetic factors (Bouchard et al., 1990).

Further to the heritability studies, a biological basis for obesity has been established through the discovery of leptin hormone which is now considered one of the well-known markers for obesity (Schonfeld-Warden & Warden, 1997). Leptin is a hormone released by adipocytes and is known to control energy homeostasis (Friedman, 2011; Friedman & Halaas, 1998; Myers et al., 2010; O'Rahilly et al., 2003; Yang & Barouch,

2007). Reduced levels of leptin lead to increased appetite and food consumption and as a result, obesity (Yang & Barouch, 2007). A leptin intervention resulted in a significant weight reduction (Halaas et al., 1997; Montague et al., 1997). Notably, it is the case that only severe cases of obesity have been associated with leptin deficiency, while other obese individuals have increased levels of the hormone (Yang & Barouch, 2007). The existence of obesity and increased levels of leptin is known as 'leptin resistance' (Myers et al., 2010). The majority of obese individuals are resistant to leptin, therefore, obesity is hypothesised to be the result of this phenomenon (Friedman, 2011) rather than due to leptin deficiency.

A review of the genetic differences in childhood obesity concluded that the majority of cases appear to have a genetic susceptibility which makes them favour obesogenic behaviours in an environment with obesogenic conditions (Bouchard, 2009). Despite the fact that genetic factors have been associated with the regulation of body weight, the significant rise in obesity prevalence in the past decades has been attributed primarily to behavioural and environmental factors (WHO, 1998). The WHO has made it clear that the increase in obesity prevalence has taken place so rapidly that there could be no significant change in the genes of the populations (WHO, 2000a) and this therefore indicates that genetic factors cannot be the sole cause of obesity.

2.1.4 Predictors of obesity in childhood

Several parental and early life characteristics have been shown to increase obesity risk in childhood.

A prospective cohort study which included 8,234 seven year old children and a subsample of 909 children who were taking part in the Avon Longitudinal study, identified early life characteristics which increased the risk of excess weight in children (Reilly et al., 2005). These included 'parental obesity, very early BMI or adiposity

rebound, more than eight hours spent watching television per week at three years of age, catch-up growth, standard deviation score for weight at age eight months and 18 months, weight gain in the first year, birth weight and short sleep duration at the age of three years' (Reilly et al., 2005, p.1). The authors highlighted that prior to their research, almost all of the factors that had been hypothesised as increasing the risk of obesity in childhood, were potential rather than confirmed, and that their study offered confirmation of the hypotheses (Reilly et al., 2005). A recent cohort study of 1,521 children from Sicily aged 9 to 14 years examined the impact of factors in early childhood and factors in parents, on childhood weight (Parrino et al., 2016). The study found that breastfeeding was a protective factor against unhealthy weight (OR=0.64; $p<0.001$). In contrast, birth weight of greater than or equal to 4 kg increased the likelihood of unhealthy weight in childhood (OR=1.83; $p<0.05$).

2.1.4.1 Adiposity rebound

Adiposity rebound (AR) is the stage in childhood at five to six years, where BMI follows a decreasing trend and body fatness declines to a minimum, before it starts to increase again into adulthood (Ebbeling, Pawlak & Ludwig, 2002; Whitaker et al., 1998). Early AR has been shown to increase the risk of becoming obese later in life (Reilly et al., 2005), however, the biological importance of this association still remains unclear.

The role of AR in predicting obesity was identified in a study of 151 children which showed that an early rebound (before 5.5 years) was associated with a greater weight gain when compared to a rebound after seven years of age (Rolland-Cachera et al., 1984). In the same study, AR at a younger age was shown to increase metabolic risk (e.g. higher glucose, insulin resistance etc) at seven years. Although obesity appeared to explain many of the relationships identified, the authors concluded that other factors

(i.e. accelerated skeletal maturation) may also have a role (Rolland-Cachera et al., 1984). Another longitudinal study in 271 children also showed that early AR (< 4 years of age) related to a higher BMI and increased metabolic risk at later life (Koyama et al., 2014). In addition, early age at AR is associated with early puberty and increased amounts of subcutaneous fat (Ohlsson et al., 2012).

Despite the evidence above, others have suggested that age at AR should not be considered a critical factor for later obesity. For example, Cole (2004) argued that although early AR can predict later obesity, this was because it identifies children with high BMI, and these are the children who are most likely to have an increased BMI later in life. He therefore suggested that crossing a BMI centile can be a better indicator of later adiposity than the timing of adiposity rebound (Cole, 2004). Overall, it appears that although early AR may not accurately predict obesity risk, it could be a good indicator of future metabolic risk.

2.1.4.2 Parental obesity

Whitaker et al. (1997), highlighted the role of parental obesity as a risk factor for obesity in children and concluded that increased obesity risk in children with one or both obese parents, is probably due to shared genetic or familial factors. Another study showed that girls from families who were in the obesogenic cluster had significantly higher BMI and skinfold thickness at age seven compared to girls from non-obesogenic families (Davison & Birch, 2002). Furthermore, in a longitudinal study of 219 Australian families, the BMI at the age of 18 years, in both sons and daughters, was significantly predicted by their mothers' and fathers' BMI (Burke, Beilin & Dunbar, 2001); this finding was independent of the alcohol intake of the children, their smoking and physical activity status, as well as being independent of the parents' educational level, and, in the case of the daughters, the alcohol intake of the father.

Recent studies also provide further evidence of the impact of parental obesity on their children's risk of obesity. A cross sectional study in Iran which included 1,189 children aged 12 to 14 years found that the weight status of children as measured by BMI, was significantly related to parental BMI. In their analysis, paternal BMI was significantly related to BMI in boys (OR=2.02) and in girls (OR=1.59), while maternal BMI only related to girls' BMI (OR=0.514) (Shafaghi et al., 2014). Furthermore, data from the Helsinki Birth Cohort Study of 2,003 individuals, showed that mother's BMI positively related to their offspring's BMI (Eriksson et al., 2015). The review by Parrino et al. (2016) showed that children who had an overweight or obese mother or an overweight or obese father had an increased risk of obesity in childhood. Lastly, analysis of data from several national cross sectional studies in Scotland which included 1651 households with parents and children 2 to 15 years of age, showed that parental obesity was responsible for 32.5% increase in risk of child obesity in the population. The authors highlighted that targeting parents with morbid obesity would reduce the overall prevalence of childhood obesity by 9% (McLoone & Morrison, 2014).

2.1.4.3 Intrauterine environment

The fetal origins of adult disease hypothesis proposed by Barker (1995) suggests that some adult diseases may have their origin in fetal development. More specifically, this hypothesis posits that adverse influences in the intrauterine environment (i.e. undernutrition during pregnancy) can affect the growth of the fetus, which in turn can impact on birth outcomes and programme chronic conditions in adult life such as coronary heart disease and type 2 diabetes (Barker 1997).

On the assumption that birth weight is associated with weight in adult life, Whitaker and Dietz (1998) summarised the evidence and indicated that intrauterine environment may affect the risk of later obesity. They examined possible mechanisms for maternal factors

increasing obesity risk in children. From the maternal factors examined (diabetes, obesity, pregnancy, weight gain) the role of maternal diabetes was found to have the strongest influence on the child's risk of obesity. The authors reported that no single mechanism could explain how these factors may affect the prenatal environment and thereby increase the risk of obesity in the fetus, however, they suggested that a common element is the increased transfer of nutrients from the mother to the fetus, which might affect the organs involved in energy metabolism. In another review, it was pointed out that a parental diet consisting of high fat before the intrauterine developmental stage may increase the accumulation of body fat in their children (Wu & Suzuki, 2006).

In relation to the impact of intrauterine environment on the risk of obesity, a historic cohort which included 300,000 young adult males who were pre- or postnatally affected by the Dutch famine (1944 to 1945), also found that in those whose mother had suffered food shortage during the first half of pregnancy, obesity rates were higher (Ravelli, Stein & Susser, 1976).

2.1.5 Potential consequences of obesity

The alarming increase of obesity in children is of great concern because of its negative short- and long-term outcomes on health and the adverse impact on society overall (Valerio et al., 2014). While obesity in children was initially considered a cosmetic problem, it is now recognised that the condition is linked to disease and morbidity (Rudolf, 2004).

2.1.5.1 Psychological impact

Obesity has been linked to several psychological and emotional effects on children and adolescents (CDC, 2015). Depression is common in young people who seek obesity treatment (Morrison et al., 2015).

Findings from the Millenium Cohort Study in the UK, which included a representative sample of children (n=11,202) aged three and five years, showed that childhood obesity was associated with behavioural and emotional problems, including hyperactivity, inattention problems, issues with peer relationships and prosocial behaviours and that obese boys were particularly at risk (Griffiths, Dezateux & Hill, 2011). The peer relationships of five to six year olds were found to be different according to the child's level of overweight and gender, and obese boys were found to be at particular risk of hyperactivity and of being exposed to peer victimisation (Seçer, Gülay Ogelman & Önder, 2015). A systematic review showed that as they reached adolescence, a significant reduction in self-esteem among obese individuals was observed (Griffiths, Parsons & Hill, 2010). Higher rates of other mental health problems such as anxiety, somatoform and eating disorders were also identified in obese adolescents (Britz et al., 2000), while an inverse relationship between children's health-related quality of life (HRQOL) and BMI has also been shown (Tsiros et al., 2009). Furthermore, obese girls in the general population were shown to have greater dissatisfaction with their weight when compared to their peers of healthy weight (Wadden et al., 1989).

In some studies however, obesity as measured by BMI did not relate to HRQOL in children (Janicke et al., 2007). It could be the case that the index used or type of obesity measured could influence the relationship between the two parameters, as Kesztyus et al. (2014) found an impact of central obesity, but not BMI, on HRQOL. Although the evidence is somewhat mixed, a recent systematic review indicated that obesity is also related to depression in children and adolescents, particularly in females (Muhlig et al., 2016).

2.1.5.2 Increased risk of non-communicable diseases

Excess weight has also been found to increase the risk of certain chronic and metabolic diseases including cardiovascular disease and type 2 diabetes mellitus, as well as a number of other co-morbidities (Lobstein, Baur & Uauy, 2004).

2.1.5.2.1 Type 2 diabetes

Previously type 2 diabetes was known as an adult disease, however, in recent years it has been increasingly diagnosed in younger people (Pulgaron & Delamater, 2014). Data from NHANES 2005-2006 on 12 to 19 year old adolescents, showed that Impaired Glucose tolerance (IGC), which is considered a pre-diabetic state, was twofold higher in overweight participants compared to the normal weight ones (Li et al., 2009). Furthermore, a recent study among 1,034 children/adolescents aged 11 to 17 years, showed that the prevalence of prediabetes and type 2 diabetes was high and that BMI scores positively related to glucose levels, and consequently diabetic status ($p=0.04$) (Al Amiri et al., 2015).

Another study of 49 obese and 25 healthy children with a median age of 13.5 years, showed that resistance to insulin differed significantly between the two groups while the expression of 70% of genes associated with type 2 diabetes was higher in the obese group, particularly in younger children (Skoczen et al., 2015). Other studies indicate that even though the prevalence of diabetes may not be as high, obese children commonly have more than one risk factor for type 2 diabetes (Batson et al., 2014; Zhu et al., 2013). Ethnicity seems to have a significant role in the onset of the disease (Bhupathiraju & Hu, 2016; Ehtisham, Barrett & Shaw, 2000) and in a study carried out by Dabelea et al. (1998) it was concluded that the prevalence of type 2 diabetes in 10-year old American Indian children was increasing over time, along with their weight.

2.1.5.2.2 Cardiovascular disease risk

A systematic review (Reilly et al., 2003) which critically appraised studies on the health effects of obesity in children reported that significant evidence existed showing that obesity related to many cardiovascular risk factors; the latter included ‘high blood pressure, dyslipidemia, abnormalities in left ventricular mass and/or function, abnormalities in endothelial function, and hyperinsulinaemia and/or insulin resistance’ (Reilly et al., 2003, p.749). Similar findings were provided by Nelson, Puccetti and Luckasen (2015), who showed that among 9,694 children (mean age of 10.3 years) participating in a community educational program, there were large numbers of children who had increased cardiovascular risk factors (i.e. high cholesterol, blood pressure, low HDL and overweight/obesity) and that all the risk factors were significantly related to obesity. A review which examined the evidence on cardiovascular abnormalities in children with obesity, found that in addition to increasing the risk of cardiovascular disease in adulthood, obesity in children also affects cardiovascular health at young age (Cote et al., 2013).

Several other studies provide support for the link between obesity and risk factors for cardiovascular disease in youth (Carolan et al., 2015). In the Bogalusa Heart Study for example, 70% of the child and adolescent participants who were obese, had at least one cardiovascular risk factor (Freedman et al., 2007); the cardiovascular risk factors that were examined were ‘triglycerides, low-density lipoprotein (LDL) cholesterol, high-density lipoprotein (HDL) cholesterol, fasting insulin, systolic blood pressure (SBP) and diastolic blood pressure (DBP)’ (Freedman et al., 2007, p.13). Left ventricular hypertrophy, which is known to significantly increase cardiovascular disease risk (Daniels et al., 2005) in adults, has been found to be related to overweight in childhood (Daniels et al., 1995) and to be highly prevalent in young patients with persistent high blood pressure (Daniels et al., 1998). Findings from a systematic review have shown

that obesity in children and adolescents also related to greater arterial stiffness which is an early marker of vascular damage (Cote et al., 2015).

2.1.5.2.3 Metabolic syndrome

A clustering of insulin resistance, obesity, high blood pressure, abnormal lipid levels and atherosclerosis (also known as metabolic syndrome), has been identified in children as young as five (Young-Hyman et al., 2001).

Metabolic syndrome, which has been related to the risk of both cardiovascular disease and type 2 diabetes (Kassi et al., 2011; Reaven, 1988), was found to be highly prevalent in a sample of 439 obese children and adolescents from the US aged 4 to 20 years (Weiss et al., 2004). The prevalence of the condition was found to increase with the severity of obesity and reached 50% in severely obese young people. Furthermore, the study reported that indicators of increased risk of cardiovascular disease are already present in these individuals (Weiss et al., 2004). Similar findings were found in a more recent study among 113 obese children from Thailand, where 50.4% of the children had metabolic syndrome (Rerksuppaphol & Rerksuppaphol, 2015) and another study in 120 Mexican obese young people where the prevalence of metabolic syndrome was 37.5% to 54.5%, depending on the criteria used (Romero-Velarde et al., 2016). A bigger study with a sample of 421 adolescents taking part in the Penn State Children Cohort Study confirmed evidence that abdominal obesity increases the burden of metabolic syndrome (He et al., 2015).

2.1.5.3 Pulmonary disorders

Obesity has also been shown to increase the risk of several conditions associated with the pulmonary system.

2.1.5.3.1 Asthma

Obesity in children and adolescents is related to asthma (Shore & Johnston, 2006; Silveira et al., 2015) however, it is not yet known whether the association is causal (Rzehak et al., 2013). Some evidence using genetic methodologies suggests that there are different pathogenetic pathways for asthma in normal-weight children and those with excess weight (Butsch Kovacic et al., 2015). A recent systematic review of prospective cohort studies showed that obesity in childhood was related to a 40% to 50% increased risk of asthma (Egan, Ettinger & Bracken, 2013) and this accords with the findings of an earlier review (Noal et al., 2011) which showed that childhood obesity related to the persistence and intensity of symptoms of asthma.

A birth cohort of infants who were followed for eight years, showed that if children were obese when they were younger than four years, then they were not at an increased risk of asthma at school age if they reduced their weight to normal by age seven. However, high BMI at seven years of age increased risk of asthma irrespective of their earlier weight (Magnusson et al., 2012). In addition, data on 12,050 children from eight birth cohort studies in Europe showed that in children who experienced a rapid increase in their BMI-SDS up to two years of age, the risk of asthma before their sixth year of life was higher compared to those who had a less marked weight gain in early life (Rzehak et al., 2013).

Another case-control study of 514 children aged 5 to 11 years showed that children who were asthmatic were more likely to have central obesity, and that overweight/obese participants as measured by BMI, were more likely to suffer from asthma [OR=1.52, 95% CI: 1.03-2.70) compared to the normal-weight control group (Papoutsakis et al., 2015). Another case-control study which included 1,264 children from Saudi Arabia aged 6 to 8 years with and without asthma, showed that BMI related to asthma in both

genders (OR=1.14, 95% CI: 1.08, 1.20 in boys and OR=1.37, 95% CI: 1.26, 1.50 in girls) (Nahhas et al., 2014). The authors concluded that allergic sensitisation may partly explain the impact of obesity on asthma in girls.

Obesity was also found to be associated with asthma as well as asthma severity/control and atopy in 351 children from Puerto Rico (Forno et al., 2014). However, another study showed that obesity did not relate significantly to asthma or to poorer control of the condition (Yilmaz et al., 2014). Results of a large international study which included cross sectional studies of 10,652 8 to 12 year old children showed that there was a strong association between BMI and wheeze, a symptom of asthma, particularly in affluent countries. The odds of overweight and obesity in relation to wheeze were OR=1.14, 95% CI: 0.98; 1.33 and OR=1.67, 95% CI: 1.25; 2.21), respectively (Weinmayr et al., 2014).

2.1.5.3.2 Obstructive sleep apnoea

Other pulmonary disorders such as obstructive sleep apnoea (OSA) have also been found to relate to overweight status in children and adolescents (Arens & Muzumdar, 2010; Han, Lawlor & Kimm, 2010; Tavasoli, Jalilolghadr & Lotfi, 2016). The prevalence of OSA, defined as “the absence of nasal airflow despite the presence of chest wall and abdominal wall movements, for a duration of at least two breaths” (Narang & Mathew, 2012, p.2) has been reported as being as high as 60% in youth (Verhulst et al., 2008). Significantly, OSA has been shown to have an adverse impact on children’s exercise performance (Evans et al., 2014).

A positive association between the degree of obesity and apnoea was found by Marcus et al. (1996), while in another study which included 399 children and adolescents 2 to 18 years of age, obesity increased the risk of OSA by 4.5 (Redline et al., 1999). The reason for the high prevalence of this condition in obese children when compared to the

healthy population has not been elucidated, even though several possible mechanisms for this association have been suggested, including changes in the anatomy and function of the upper airway, in lung mechanics and ventilatory control (Arens & Muzumdar, 2010).

2.1.5.4 Musculoskeletal problems

Obese individuals are at increased risk of developing musculoskeletal problems, including fractures, disability and decreased mobility due to the increased burden that the excess weight poses on the musculoskeletal system (Anandacoomarasamy et al., 2007; Taylor et al., 2006). Furthermore, several musculoskeletal conditions appear to be due to, or worsened, by obesity in children (Esposito et al., 2013).

In fact, Paulis et al. (2014) recently demonstrated via their systematic review that excess weight was associated with physical ‘pain, injuries and fractures’ (Paulis et al., 2014, p. 15) in early childhood while other data show that obesity affects a child’s locomotor system both in terms of structure and function (Chan & Chen, 2009). The two most common orthopaedic complications in children related to obesity, include Blount’s Disease (Tibia vara) (Dietz, Gross & Kirkpatrick, 1982; Gordon et al., 2006) and slipped capital femoral epiphysis (Murray & Wilson, 2008) both of which result from the adverse effect of excess weight on children’s developing musculoskeletal system (Daniels, 2009).

The negative impact of obesity on the musculoskeletal system may also be responsible for the continuous accumulation of excess weight in overweight/obese children, as their overweight status is likely to affect their participation in physical activity (Taylor et al., 2006). Although this is not yet proven, it could also be that changes to the foot morphology may also keep obese children less active due to discomfort. It has been shown that the foot morphology is affected from the excess weight with flat feet being

more common in overweight children (Mauch et al., 2008). Other consequences of obesity in relation to the musculoskeletal system, include osteoarthritis, body pain, gait disturbance and gout (Anandacoomarasamy et al., 2007; CDC, 2015).

2.1.5.5 Cancer

Other significant health consequences of childhood overweight and obesity which may not appear until adulthood include certain types of cancer (De Pergola & Silvestris, 2013; Larsson & Wolk, 2007). According to the World Cancer Research Fund (2016) there is strong evidence that excess weight increases the risk of 11 types of malignancies including endometrial, oesophageal (adenocarcinoma), pancreatic, kidney, liver, prostate (advanced), bowel, postmenopausal breast, gallbladder, ovarian and stomach cancers. The link between obesity and risk of several types of cancer in adults was confirmed in a systematic review (and meta-analysis) of prospective studies which showed that high BMI related to a number of common and less common cancers; for some types of cancer, it was indicated that the associations differed according to gender and ethnic origin (Renehan et al., 2008).

In fact, obesity is reportedly responsible for 20% of all malignancies (Wolin, Carson & Colditz, 2010) and its influence has been found to relate to gender and the affected site (De Pergola & Silvestris, 2013). A recent study which used data from 155,505 Danish girls aged between 4 to 14 years showed that a greater increase in BMI was associated with a greater risk of endometrial cancer in later life (Aarestrup et al., 2017). Another study analysing data from a cohort of 2,347 participants aged 2 to 14 years, found that for every SD increase in BMI in childhood, there was a 9% increase in risk of developing cancer in adult life (Jeffreys et al., 2004); the risk for developing smoking related cancers per SD increase in childhood BMI was 30%. Furthermore, increased weight in adolescence was found to increase mortality risk from colon cancer in

adulthood by twofold (Bjorge et al., 2008). Lastly, a case-control study which examined the association of obesity and gastric cancer risk in 1,492 adolescents with gastric cancer and 1,492 controls showed that higher BMI at 18 years was related to a higher risk of gastric cancer in adulthood (Song et al., 2015).

2.1.5.6 Adulthood obesity and morbidity

Obese children not only have a higher risk of being obese in their adult life, but they are also more likely to suffer from greater morbidity and mortality when they are adults (Biro & Wien, 2010; Dietz, 1998; Jordan et al., 2016; Venn et al., 2007; WHO, 2016b).

In a cohort study of 7 to 15 year old Australian children (N=8,498) those who had been obese in their childhood had a significantly higher relative risk (RR) of becoming obese in their adulthood than those who had a normal weight in their childhood (RR=4.7; 95% CI: 3.0, 7.2 for boys and RR=9.2; 95% CI: 6.9, 12.3 for girls) (Venn et al., 2007). Furthermore, in the same study, 6.4% and 12.6% of adult obesity (in males and females respectively), was attributed to their obese status in childhood (Venn et al., 2007).

Whitaker et al. (1997), indicated that in children above six years old who were obese, the probability of being obese in adult life exceeded 50% compared to an approximately 10% probability in their non-obese peers. A study by Power et al. (1997) showed that, the older the children when obesity was diagnosed, the greater risk that obesity would persist into adult life. Children who were aged above five years and were obese, were more at risk of the condition persisting, and also more likely to remain obese in their adult life than children who were obese before they reached five years of age (Power et al. 1997).

The notion that adulthood obesity is determined by obesity in childhood has been recently questioned in a systematic review and meta-analysis. The review showed that 55% of children who are obese are also likely to be obese as adolescents and 80% of

adolescents will still be obese when they reach adulthood. However it also showed that 70% of obese adults were not obese when they were children or adolescents, and the authors concluded that overall adult obesity does not appear to be determined by childhood obesity (Simmonds et al., 2016).

Recent evidence from the Northern Finland Birth Cohort confirms previous findings of the persistence of childhood obesity and the greater risk for morbidity in adult life. This population-based study which collected data on 4,111 individuals at preschool age and at age 30 years, showed that high preschool BMI related to general and central obesity in adult life and earlier appearance of metabolic syndrome (Graversen et al., 2014). In particular, children within the 5% highest BMI at five years of age, had a 6.2 relative risk (95% CI: 4.2, 9.3) of obesity in adulthood, a relative risk of 2.4 (95% CI: 2.0, 2.9) for central obesity and 2.5 relative risk (95% CI: 1.7, 3.8) for early onset of metabolic syndrome.

A prospective cohort study in the US showed that obesity in children also increased the risk of high blood pressure in adults; more specifically, the risk of developing adult hypertension was 26% for obese children compared to the 6% for normal weight peers (Watson et al., 2013). Another study found that high BMI during childhood or adolescence increases cardiovascular disease risk in adult life (Power, Lake & Cole, 1997). The authors reported that the findings indicate a need to tackle obesity early in life. A systematic review which critically examined the consequences of childhood obesity concluded that the cardiovascular impact of childhood obesity persists and that there is strong association between obesity in childhood and morbidity/mortality in adult life (Reilly et al., 2003).

2.1.5.7 Economic Burden

In addition to the impact on health, obesity has also been shown to negatively affect a country's healthcare system and the economy. The two types of costs that obesity has on the economy include the direct ones, which are those resulting from treating obesity (surgery, medical tests, drug therapy) and the indirect ones which arise from the impact of obesity on work productivity, wages and insurance (Harvard School of Public Health, 2017; Lobstein, Baur & Uauy, 2004).

The Australian Diabetes, Obesity and Lifestyle study, using data available for 1999-2000 and 2004-2005 showed that the total cost of overweight/obesity (as defined by BMI) on Australia economy was \$56 billion/year, with \$21 billion/year being the direct obesity healthcare costs and the other \$35.6 billion/year being the estimated indirect costs (Colagiuri et al., 2010). In the US, it was estimated that in 2005, the amount spent on healthcare for obesity was \$190 billion (Cawley & Meyerhoefer, 2012) while for the period between 2003 and 2013, the annual healthcare and productivity loss costs in asthmatic employees due to excess weight was estimated to be \$878 and \$256, respectively, per person (Chang et al., 2017; Martin-Calvo, Moreno-Galarraga & Martinez-Gonzalez, 2016).

In the UK, the National Audit Office (NAO) reported that in 1998 £9.4 million pounds was spent on treating obesity, while another £469.9 million was spent on treating diseases attributable to obesity. Furthermore, the estimated indirect cost of obesity was £2.1 billion (National Audit Office, 2001). According to Scarborough et al., (2016) the cost of excess weight to the UK's National Health System (NHS) between 2006 and 2007 was £5.1 billion. Other estimates have shown that, in 2007, direct costs to the UK's (NHS) in relation to overweight and obesity and related morbidities amounted up

to £4.2 billion pounds, while the indirect costs of obesity on the wider economy were approximately £15.8 billion (Wang et al., 2011).

Another estimate has shown that the direct costs to UK's NHS attributable to obesity are approximately £4.2 billion, while, if current trends continue, this cost is expected to more than double by 2050 (Department of Health, 2011a). It has further been estimated that by 2030, the combined medical costs associated with treating obesity related diseases in UK will increase by £192 billion per year (Wang et al., 2011).

2.1.6 Methodological aspects-Assessment methods of body composition

Several methods exist for assessing weight status or body composition in children and adults. These can be divided into the 'proxy methods' and the 'laboratory measurements' (Hu, 2008). The proxy methods are commonly used in large epidemiological studies or routinely in clinical practice and are the ones employed in the current PhD work. The ones used in a laboratory setting are considered to be more reliable, accurate and advanced and are used to validate other methods that assess body composition (Hu, 2008).

Below is a brief overview of the most common methods in the two categories of assessment. The following section includes a basic description of their methodology, their advantages and disadvantages, as well as their applicability in research.

2.1.6.1 Laboratory methods

2.1.6.1.1 Hydrodensitometry-underwater weighing

This is an underwater weighing method that measures total body density and involves individuals (wearing a swimming suit) being measured while being submerged in a tank (Bray et al., 2002; Hu, 2008). It is based on the principle that fat is not as dense as the

water is, and therefore individuals with a higher percentage of body fat, will have lower body density as compared to those with less fat (Hu, 2008).

Hydrodensitometry is considered to be a gold standard method for assessing body composition and is commonly used in validation studies (Hu, 2008). It is generally not considered a good method for children, as it requires active collaboration from the participants and it is also time consuming. The equipment involved is very expensive and therefore it is not practical to use in large epidemiological studies (Hu, 2008).

2.1.6.1.2 Dual Energy X-ray Absorptiometry- (DEXA)

The DEXA machine uses low level radiation to measure fat and lean tissue, bone mineral content and density with participants lying in supine position (Taylor et al., 2002). It is considered an accurate method for assessing body composition and it is relatively quick and simple. As it exerts only a low level of radiation, it can be used in children (Wells & Fewtrell, 2006).

However, the equipment required is very expensive and cannot be moved and as such is not frequently used in epidemiological studies with large sample sizes. Furthermore, DEXA cannot distinguish between different types of fat: for example visceral fat (which is found around the organs) or subcutaneous fat (which is located under the skin) (Hu, 2008).

2.1.6.1.3 Computed Tomography (CT) and Magnetic Resonance Imaging (MRI)

CT and MRI are imaging techniques that provide cross-sectional scans of tissues or organs and are used for the assessment of body composition and regional body composition at the organ and subcutaneous level (Hu, 2008; Wells & Fewtrell, 2006). CT, but not MRI involves some level of radiation.

They are both considered very accurate methods for measuring body composition, however they are not commonly used in epidemiological studies due to their cost, immobility, limited availability and the fact that CT exerts radiation (Hu, 2008; Wells & Fewtrell, 2006).

2.1.6.1.4 Air Displacement Plethysmography (ADP)

This method is based on the same principles of hydrodensitometry, however the measurements are taken in air, with participants in a swimming suit being stationed in a small chamber (Hu, 2008). It is considered an accurate and precise method of assessing body composition and is safe and practical to use in children as young as four years (Wells & Fewtrell, 2006). However, it is very expensive and therefore its application is limited (Hu, 2008).

2.1.6.1.5 Bioelectrical Impedance

This method is commonly used to assess body composition and is considered to be simple, non-invasive and the equipment used is portable (Wang & Hui, 2015). Although traditionally, this method involved attaching electrodes to the participants lying in supine position, more recently the hand (or foot) to foot system has increased in popularity (Dehghan & Merchant, 2008). Bioelectrical impedance is based on the principle that body composition affects the rate with which the electric current travels through the body and that fat delays the electric current more than lean mass or water does (Dehghan & Merchant, 2008). Based on the difference in conductivity, the lean and fat mass as well as body water are then calculated through the use of equations (Hu, 2008). As this method measures body water, the hydration status of the individual as well as disease status can affect the measurements (Hu, 2008). Body structure and ethnicity can also influence the accuracy of this method (Wang & Hui, 2015).

BIA has been shown to be a good method in measuring body fat in healthy weight adults (Sun et al., 2005), however, the estimation of body fat in lean and obese individuals was not found to be consistent with gold-standard methods (e.g. DEXA). Further studies in children and adolescents who have validated BIA devices against standard methods have shown that BIA methods tend to overestimate or underestimate percentage body fat in this population (Wang & Hui, 2015; Silva et al., 2013). A systematic review which examined the validity, reliability and measurement error of this method in measuring body fat in children and adolescents concluded that although it has good reliability and it is a practical method to use in this population, its validity and measurement error are not satisfactory (Talma et al., 2013). Furthermore, skinfolds measurements have been shown to be better alternatives rather than BIA when standard methods are not available (Jensen, Camargo & Bergamaschi, 2016).

2.1.6.2 Anthropometry

Anthropometric methods, which are the main focus of this literature review and PhD work, are the most common indicators used to assess growth and development in children and adolescents, and are generally considered to be simple, inexpensive, safe and non-invasive (Jensen, Camargo & Bergamaschi, 2016; Lahti-Koskia & Gill, 2004; Li et al., 2015a). They have also been shown to have strong correlation with a child's nutritional status (Li et al., 2015a).

An important aspect that needs to be taken into account in studies which involve anthropometric evaluations, is the training of the health professional/researcher and the calibration of the equipment used (NHANES, 2004; Hu, 2008). Anthropometric measurements that are commonly used in the research setting and are proxies of a child's nutritional or weight status, include BMI, waist and hip circumference, waist-to-hip circumference and skinfold thickness.

A description of each method is given below, together with their advantages and disadvantages.

2.1.6.2.1 BMI

Body Mass Index [$\text{BMI} = \text{weight}(\text{kg}) / \text{height}(\text{m})^2$] is the most common indicator used to determine weight status in children and adults (WHO, 2016c).

The use of BMI in determining obesity in children is widely recommended, as it constitutes a method which is cheap and simple to apply both in research and the clinical setting. There has also been recent evidence from a systematic review favouring the use of BMI in assessing children's body fat when other more accurate methods such as DEXA are not available (Martin-Calvo, Moreno-Galarraga & Martinez-Gonzalez, 2016). Taking into consideration that BMI is easy to use, safe and well tolerated by children, this method is useful in epidemiological studies which include children (Jensen, Camargo & Bergamaschi, 2016).

In several studies, BMI has been found to correlate well with measurements obtained using gold standard methods, particularly DEXA. Although conducted in adults, Blew et al. (2002) showed that in 318 postmenopausal women, a moderately high association existed between BMI and % body fat as measured by DEXA ($R=0.81$). In a cohort of adolescents aged 11 to 17 years BMI measurements also correlated with DEXA outcomes (%BF $r=0.85$, $p<0.001$; FBM $r=0.95$, $p<0.001$) (Steinberger et al., 2005). Similar findings arose from a study of 1,110 children aged 6.35 to 10.9 years ($r_s=0.83$) (Boeke et al., 2013) and another survey which included 96 girls aged 4 to 16 years ($r=0.934$) (Goulding et al., 1996).

In addition, in 5 to 19 year old individuals it has been shown that BMI is moderately associated to assessments of total body fat ($R^2=0.85$ for boys and 0.89 for girls) and percent body fat ($R^2=0.63$ for boys and 0.69 for girls), as determined by DEXA

(Pietrobelli et al., 1998). The latter authors recommended the use of BMI in assessing fatness in children and adolescents, however they reported that when making comparisons of BMI across groups of different age, findings should be interpreted with caution. Finally, BMI has recently been shown to be a good indicator in identifying dyslipidemia among 2,243 children aged 7 to 17 years with 77% accuracy (Zhu et al., 2016).

The systematic review by Jensen, Camargo & Bergamaschi (2016) indicated that a moderate positive association exists between BMI and body fat as estimated by DEXA, while amongst the different anthropometric methods tested, BMI was found to be a very specific but less sensitive method. Similarly, in their review Martin-Calvo, Moreno-Galarraga and Martinez-Gonzalez (2016) showed that BMI measurements in children strongly related to that of DEXA (r^2 : 0.32-0.91). Despite its moderate sensitivity, BMI has been suggested in two other recent systematic reviews and meta-analyses, as a reasonably good measure with sufficient specificity to make it appropriate for use in epidemiological surveys (Javed et al., 2015; Simmonds et al., 2014). Similarly, a review of evidence indicated that BMI is a valuable measure in children as long as the limitations in its applications are taken into account (Doak et al., 2013) even though others have highlighted the need to find alternative methods for defining obesity in children (Brown et al., 2016).

With regard to the capacity of childhood BMI to predict obesity-related morbidities in adulthood, a recent systematic review and quantitative analysis showed that even though childhood obesity related to moderate increased risks of morbidity in adulthood, the magnitude of the risk could not guarantee the ability of BMI in childhood to predict morbidity in adult life. This was because those who suffered from obesity-related morbidities in adulthood were often healthy as children (Llewellyn et al., 2016).

2.1.6.2.1.1 Reference standards

Defining overweight and obesity in individuals younger than 18 years is not as easy as it is in adults; in fact, there is no universal agreement as how this should be done (Flegal, 1993) and there is no consistency in how obesity in children is classified (Rudolf, 2004).

As mentioned at the beginning of this chapter, in adults a BMI of 25 kg/m² to 29.9 kg/m² is commonly used to define overweight and a BMI of 30kg/m² or above indicates obesity (WHO, 2016c). These classification cutoffs have been derived based on morbidity and mortality outcomes from different sources (Hu, 2008).

In children, however, no absolute consensus exists and evidence to support such a classification is limited (Lahti-Koskia & Gill, 2004). Interpreting BMI measurements in children is also more complicated as BMI is not a static measure and because it varies between girls and boys. For this reason, it is suggested that BMI should be interpreted using percentile measures, also known as population or growth standards (Scottish Intercollegiate Guidelines Network, 2010a). These are defined in relation to a reference population after taking into account parameters such as age, gender and ethnic status (Troiano & Flegal, 1998).

2.1.6.2.1.2 z-scores vs percentiles

Children's weight status is commonly interpreted/presented with the use of percentiles or z -scores. The latter is calculated as follows (WHO, 1997b):

$$z - \text{score (or SD - score)} = \frac{(\text{observed value} - \text{median value of the reference population})}{\text{standard deviation value of reference population}}$$

Although the z-score is a more complicated measure compared to percentiles, its use in research is recommended for several reasons (London School of Hygiene and Tropical Medicine, 2009): the z-score is a continuous/linear measurement while the percentile is a rank scale; for this reason the former enables comparisons across different indicators

(such as age and sex) and allows for the calculation of summary statistics, including the mean and standard deviation (Wang & Chen, 2012; WHO, 1997b). Furthermore, in contrast to z-scores, percentiles cannot be used to assess the change in weight status over time (Wang & Chen, 2012). Thus, the use of z-scores is recommended in research while percentiles are commonly used in clinical practice because of their simplicity.

2.1.6.2.1.3 Classification systems

There are a number of BMI reference data sets for children, both internationally and locally developed. The most common BMI systems used for defining overweight/obesity at the international level, are those of the International Obesity Task Force (IOTF) (Cole et al., 2000), the US Centres for Disease Control and Prevention (Kuczmarski et al., 2000) and the WHO (de Onis et al., 2007).

2.1.6.2.1.3.1 *International Obesity Task Force (IOTF) cut-off values*

With the purpose of enabling international comparisons of overweight and obesity prevalence in children, rather than to replace current national growth reference data, a set of international age and sex specific centiles commonly known as the IOTF cut-offs, was developed in 2000 (Cole et al., 2000). To develop these cut offs, representative data from UK, Brazil, Hong Kong, the Netherlands, Singapore and the US were used. The sample included 97,876 males and 94,851 females aged from birth to 25 years of age.

The international BMI classification for children and adolescents up to age 18 years, is as follows:

Low= isoBMI < 25 at 18 years

Overweight= isoBMI: 25-29.9 at 18 years

Obesity= isoBMI>30 at 18 years

2.1.6.2.1.3.2 US Centers for Disease Control and Prevention/ BMI-for-age centiles

The US CDC 2000 growth charts were developed using data collected between 1963 to 1994 from five NHANES and five supplementary data sources (Kuczmarski et al., 2000).

The age and sex specific percentiles for children aged 2 to 19 years are the following:

Underweight= <5th percentile;

Normal= $\geq 5^{\text{th}}$ <85th percentile;

Overweight= $\geq 85^{\text{th}}$ and < 95th percentile;

Obese= >95th centile.

2.1.6.2.1.3.3 WHO (AnthroPlus)/ BMI-for-age (5-19 years)

Using similar NHANES data, the WHO (de Onis et al., 2007) then developed growth references for use in individuals between 5 and 19 years old:

Overweight: >+1SD (equivalent to BMI 25 kg/m² at 19 years)

Obesity: >+2SD (equivalent to BMI 30 kg/m² at 19 years)

Thinness: <-2SD

Severe thinness: <-3SD

2.1.6.2.1.3.4 National context

Only a few countries, including the UK, have developed national growth reference standards. Using the LMS method (Cole, 1990), the updated British growth reference centiles were based on anthropometric data for weight, height, BMI, and head circumference from 17 separate surveys that used representative samples from England, Scotland and Wales. The sample comprised a total of 37,700 children aged 23 weeks gestation to 23 years (Cole, Freeman & Preece, 1998).

The resulting child BMI centile classification system, commonly known as the 1990 UK population cut points, is as follows:

Underweight: $\leq 2^{\text{nd}}$ centile;

Healthy weight: $> 2^{\text{nd}}$ - $< 85^{\text{th}}$ centile;

Overweight: $\geq 85^{\text{th}}$ centile;

Obese: $\geq 95^{\text{th}}$ centile.

These are the standards that are being used for population monitoring/research setting and are slightly lower than the clinical ones, in which obesity is defined as at, or above the 98th centile and overweight between 91st and 97th BMI centiles. These thresholds are biologically meaningful as the risk of morbidity has been shown to increase above the 95th centile (Reilly et al., 2003).

2.1.6.2.1.3.5 *National or International Growth Standards?*

Although most definitions of obesity in youth are based on centiles that are age and gender specific, the use of different classification systems can produce a significant variation (Flegal & Ogden, 2011). Thus, an effort has been made to standardise a classification system for international use (Cole et al., 2000), but its use is not currently recommended.

In a mini review which examined whether childhood obesity should be defined using national reference data or international classification, it was concluded that the use of a universal definition was not as yet supported by the evidence available (Reilly, 2002). This review recommended using a definition based on national reference data, as this would provide a more reliable, safe and evidence-based approach to the definition of obesity in children (Reilly, 2002). This approach was also supported by expert committees in the field (Barlow & Dietz, 1998; Wright et al., 2002). Furthermore, in the UK, the National Institute for Health and Care Excellence (NICE) and the Scottish

Intercollegiate Guidelines Network (SIGN) have also supported the use of the locally developed UK 1990 BMI growth reference charts (National Institute for Health and Care Excellence, 2014; Scottish Intercollegiate Guidelines Network, 2010b).

2.1.6.2.2 Waist circumference and Waist-to-hip ratio

Waist circumference and waist-to-hip ratio are considered indirect proxies of central obesity and are increasingly being used as complementary measures of obesity. The former is commonly measured at the narrowest points of the mid-section while the hip circumference is generally taken at the widest protrusion of the gluteal muscles; in both cases, the tape is perpendicular to the floor (ISAK 2001). Both are very simple and inexpensive measures to obtain, even though they are prone (particularly the second one) to measurement error (Hu, 2008; Verweij et al., 2013).

Waist circumference in particular has been shown to relate strongly to more accurate methods of body fat assessment and can reliably indicate health risk particularly in adults (Rimm, Hartz & Fischer, 1988; Wells & Fewtrell, 2006). Furthermore, it has been shown to perform relatively well as a measure of abdominal fat mass in 301 preschool children, when compared to DEXA measurements (Taylor et al., 2008). A recent systematic review comparing methods of measuring body fat in children aged 7 to 10 years, recommended the use of waist circumference when more accurate methods, including DEXA, are not available (Jensen, Camargo & Bergamaschi, 2016). Similar recommendations were given by another recent systematic review and meta-analysis which examined the relation between waist-to-height ratio and body fat as measured by DEXA (Martin-Calvo, Moreno-Galarraga & Martinez-Gonzalez, 2016). Among several other anthropometric indicators such as skinfolds and BIA, waist circumference was found to have the strongest link with air displacement plethysmography (Michels et al., 2013).

Although the ability of waist circumference to predict disease in youth is not yet well established, in the Bogalusa Heart Study central obesity in children and adolescents aged 5 to 17 years adversely related to levels of triglycerides, LDL and HDL cholesterol, and insulin (Freedman et al., 1999). There is some evidence that waist circumference predicts morbidity in children and it has been suggested that compared to BMI, waist circumference and waist-to-hip ratio can better predict risk of cardiovascular disease (Savva et al., 2000). The National Obesity Observatory (2009) suggested that in adults using waist circumference with BMI offers the best means of identifying individuals who are at increased risk for morbidity related to obesity.

In contrast to BMI, however, no consensus exists as to which cut off points are to be used for the definition of central obesity in children. This is because the threshold for central obesity predicting morbidity in young people is not known (Lahti-Koskia & Gill, 2004). In the UK it is recommended that waist circumference in children and adolescents be used as a complementary measure (National Institute for Health and Care Excellence, 2014). Furthermore, differences in protocols and difficulties encountered in obtaining good measurements in children, particularly in children with increased weight, indicate that further work needs to be conducted before waist circumference is routinely adopted in obesity research (Rudolf, 2004).

2.1.6.2.3 Skinfold thickness

This method assesses subcutaneous fat (located directly under the skin) in various sites of the body. It involves folding the skin and fat underneath and measuring it with calipers (Public Health England, 2016a). Thereafter, equations are used to calculate the percentage of body fat.

Skinfold thickness is a fast, easy and inexpensive method and it has been shown to relate relatively well to more accurate methods of body fat assessment such as CT and

DEXA (Hu, 2008; Lahti-Koskia & Gill, 2004). In children 8 to 12 years old, skinfold measurement gave relatively good estimations of total body fat when compared with those obtained from MRI (Chan et al., 1998). Also, triceps skinfold was found to correlate well with estimates of body fat from DEXA in Portuguese children aged 10 to 15 years (Sardinha et al., 1999). The accuracy of triceps and subscapular skinfold for assessing body fat in children and adolescents aged 8 to 19 years were tested against DEXA and they were shown to be valid measurements in identifying both obese and underweight children (Freedman et al., 2013). Furthermore, a relatively strong association between DEXA and the sum of six skinfolds was identified in a study on 38 obese children and adolescents at baseline (Watts et al., 2006). However, skinfold measurements were not found to accurately measure changes in body fat.

The evidence as to whether skinfold measurements can predict disease risk is equivocal (Freedman et al., 2009; Kim, Meade & Haines, 2006; Menotti et al., 2005). Furthermore, although skinfold thickness is a simple procedure to perform, this measurement is not as reproducible as other methods. It can be difficult to obtain from obese participants and there can be large inter-observer errors. In addition, similar to waist circumference, the lack of cut off points limits its usefulness in defining obesity in children (Lahti-Koskia & Gill, 2004). The accuracy of this method could also vary based on the site and equation used (Freedman et al., 2009).

Overall, the evidence favours the use of anthropometric measures, particularly BMI and waist circumference for assessing body fat in children, when more accurate methods such as DEXA and ADP are not available (Jensen, Camargo & Bergamaschi, 2016).

2.2 Caries

2.2.1 Definition of caries

Dental caries (or tooth decay) is defined as a chronic condition caused by acids that are released from bacterial fermentation of carbohydrates which subsequently diffuse into the enamel and dentine (hard tissue of the teeth) and soften the tooth minerals (Colak et al., 2013; Featherstone, 2008). The process by which calcium and phosphate are lost from the enamel is called demineralisation. Repeated cycles of demineralisation and remineralisation result in the formation of a small lesion which can then lead to cavitation (or a hole in the tooth) (WHO, 1962). Thereafter, the pulp of the tooth may be affected, then become infected and eventually there could be an abscess formation during which the infection reaches the tip of the root of the tooth (Frencken et al., 2011).

When the primary teeth of preschool children are affected by caries, this is known as Early Childhood Caries (ECC) (Selwitz, Ismail & Pitts, 2007). ECC has been defined as “the presence of one or more decayed (non-cavitated or cavitated lesions), missing teeth (due to caries), or filled tooth surfaces in any primary tooth in a child 72 of months age or younger. In children younger than 3 years of age, any sign of smooth-surface caries is indicative of severe early childhood caries (S-ECC). From ages three to five one or more cavitated, missing teeth (due to caries), or filled smooth surfaces in primary maxillary anterior teeth, or decayed, missing, or filled score of ≥ 4 (age 3), ≥ 5 (age 4), or ≥ 6 (age 5) surfaces constitutes S-ECC” (American Academy of Pediatric Dentistry, 2008, p.15).

In general, caries experience is measured by dmft which is an index quantifying the number of teeth that are affected by caries (decayed-d), the number of teeth extracted (missing-m), and the number of teeth which have been restored (filled-f) (Klein, Palmer & Knutson, 1938). Lower case letters refer to the primary dentition and uppercase

letters to the secondary one. Further details on the caries indices will be provided later in the thesis.

2.2.2 Caries epidemiology

2.2.2.1 Dental Caries worldwide-Prevalence and trends

Despite being a preventable disease, caries is a major public health issue worldwide (Benjamin, 2010; FDI World Dental Federation, 2015; Petersen et al., 2005) and has been characterised as a ‘silent epidemic’ by the US Surgeon General (Benjamin, 2010). It is one of the most common conditions in the childhood population (FDI World Dental Federation, 2015) and affects 60-90% school-aged children in many developed countries (Petersen et al., 2005; WHO, 2003b).

Data analysis from the 2010 Global Burden of Disease (GBD) study (Marcenes et al., 2013), showed that between 1990 to 2010, periodontal disease, oral cancer and caries increased by 45.6% on average which was similar to the increase of non-communicable diseases such as diabetes (Jin et al., 2016). A systematic analysis of the data from the same survey showed that 3.9 billion people suffered from dental conditions and that the prevalence of untreated caries in permanent teeth was 35%. In fact, caries was identified as the most common condition among the 291 that were examined as part of the GBD 2010 (Marcenes et al., 2013).

With regard to the oral health of children in developed countries, significant improvements in dental health in recent decades have been reported, particularly for dental caries in the permanent teeth. This is probably because of improved oral health behaviours including effective use of fluorides particularly in toothpaste, water fluoridation, better management of the condition and school based prevention programmes (Petersen, 2010; Petersen & Esheng, 1998; Splieth, Christiansen & Foster Page, 2016). However, it is still evident that many children are still affected by caries

and an increase in prevalence has been reported in some countries, particularly in children of low SES (Lencova, Pikhart & Broukal, 2012; Speechley & Johnston, 1996).

Data from the 2011-2012 US NHANES showed that caries was present in the primary dentition of 23% of children aged two to five years, while an estimated three in five adolescents aged 12 to 19 years, experienced caries in their permanent teeth (Dye et al., 2015). Recently, in Greece and Iran a high prevalence of caries has been reported in children attending first or sixth grade of elementary schools and among those aged two to three years, respectively (Toutouni et al., 2015; Tsanidou et al., 2015). Other recent surveys in Poland, Chennai, Sudan, Australia, Saudi Arabia and Bosnia and Herzegovina, which included mostly younger children, have also found that caries is still highly prevalent in these populations (Al-Meedani & Al-Dlaigan, 2016; Arangannal, Mahadev & Jayaprakash, 2016; Baginska et al., 2016; Elidrissi & Naidoo, 2016; Sacic et al., 2016; Smith et al., 2015). In Western Australia, dental caries was responsible for a significant number of admissions to hospitals among preschool and primary school children (Tennant et al., 2000).

Although dental caries levels in developing countries were low until fairly recently, the prevalence and severity of the condition has started to increase, presumably because of increased sugar consumption and limited exposure to fluorides (Petersen et al., 2005).

Oral health inequalities are also evident. In the US, for children aged three to five and six to nine years, untreated dental caries was significantly higher for those living at or below the poverty level when compared to their peers living above the poverty threshold, while dental sealants were more common among children aged six to nine years living in higher income households (Dye, Li & Thornton-Evans, 2012). Furthermore, cavities in US children aged two to five years increased by 16.6% between 1988 and 2004 (Dye et al., 2007), while Mexican-American children in the same age

range were found to be more likely to suffer more caries compared to their non-Hispanic black and non-Hispanic white peers (Dye et al., 2004). These disparities persisted in a survey examining dental caries in 2011-2012 which showed that the prevalence of the condition was higher in children that had Hispanic (46%) and non-Hispanic black (44%) origin, than in those of non-Hispanic white background (Dye et al., 2015). More evidence indicating the presence of oral health inequalities comes from the prevalence of caries in underprivileged children in Canada. When the prevalence of ECC was examined in a sample of maltreated children, it was found that abused and neglected children had higher levels of tooth decay compared to the five year old population of Toronto (Valencia-Rojas, Lawrence & Goodman, 2008).

2.2.2.2 UK prevalence and trends

With regard to caries in the UK, the Children's Dental Health Survey (CDHS) (Health and Social Care Information Centre, 2015), provides estimates on the oral health of children aged 5, 8, 12 and 15 years studying in mainstream and independent schools in the UK. The 2013 survey on English children (Health and Social Care Information Centre, 2015) showed that 32% and 44% of 12 and 15 year old children respectively, had obvious decay experience in their permanent teeth and these figures were lower than the corresponding ones of 41% and 55% in 2003. Thus, although there were significant reductions in the dentinal caries experience from 2003, many children continue to be affected by the condition and suffer related consequences. The same survey also showed that for five and eight year olds, 31% and 46%, respectively had obvious decay experience in their primary dentition (Health and Social Care Information Centre, 2015). It also indicated the presence of social inequalities, as children from lower income families were more likely to suffer from caries than their higher income peers.

Furthermore, results from the National Epidemiology Programme for England 2012 (Public Health England, 2013), which assesses the prevalence and severity of caries in children aged 5 and 12 years in public schools in England, showed that in 2012, caries affected almost 28% of the children aged 5 years; these children had on average 3.38 teeth affected by decay. Based on the results of this survey, there were improvements in the prevalence and severity of the condition in this population when compared to 2008. The percentage of children with decay decreased by 9.7% between 2008 to 2012, while the mean number of decayed, missing or filled teeth decreased from 1.11 in 2008 to 0.94 in 2012, indicating an improvement of 15.3% (Public Health England, 2013). A more recent survey of the National Dental Epidemiology Programme for England in the same age group indicated a further decrease in the percentage of children that are affected by decay (24.7% as compared to 27.9% in 2012), even though there was a minor increase in the mean number of teeth that were decayed, missing or filled in the children with some experience of decay (3.4 as compared to 3.38 in 2012) (Public Health England, 2016b).

Another study which examined trends in dentinal caries experience of children in the UK using data from the CDHS between 1983 to 2003, showed that although there were continuous improvements in the permanent dentition of children aged 8, 12 and 15 years of age, no statistically significant improvements were found for the primary dentition of five year old children (Pitts et al., 2006). Recently, Murray, Vernazza and Holmes (2015), examined the trends in the dental health of children in UK in the last four decades and showed that dental caries prevalence improved in both 5 and 15 year old children, however, the reduction was much greater in older children (from 72% to 41% and from 97% to 46%, respectively). In another survey, which examined the pattern of hospital admissions for dental care between 1997 and 2006 in children and adolescents aged up to 17 years, it was shown that there was a 66% increase in tooth

extractions due to caries and the most common age for extraction was five years old (Moles & Ashley, 2009). This is a disturbing finding as extraction of tooth at this age usually involves general anesthesia (Public Health England, 2013). Although this could also reflect that until 1997, extraction under GA could be done in general practice, so fewer children visited the hospitals to have their teeth extracted, it still remains a significant figure.

There also exist regional inequalities in dental caries prevalence ranging from 21.2% in the South East to approximately 35% in the North West (Public Health England, 2013). The latest National Dental Epidemiology Programme for England in five-year-olds confirmed that social inequalities in oral health persist, with poor oral health tending to be more evident in more deprived local authority areas (Public Health England, 2016b). Moles' and Ashley's work (2009) also highlighted the link between caries and socioeconomic status, as a significant relationship was shown between the number of children admitted for extractions and the deprivation of the area where they lived. Furthermore, children resident in the most deprived areas were more likely to present as an 'emergency' when compared with their peers who lived in less deprived areas (Moles & Ashley, 2009).

2.2.2.3 Dental caries in children in Plymouth-prevalence and trends

With regard to dental caries in Plymouth, data available showed that in 2009, five year old children in Plymouth had on average 0.9 teeth affected by caries, while those with some experience of decay (29.1%) had on average 3.2 affected teeth (Witton & Nelder, 2009); in 2000, the corresponding values were 1.6 and 3.7. Although an improvement in the oral health of five year olds has been shown between 2000 to 2009, the authors recommended that the findings should be cautiously interpreted due to the noticeable difference in participation rates among the two surveys (78.2% in 2000 and 39.6% in

2009) and the type of consent required for each survey (Witton & Nelder, 2009). In 2000, the survey was based on an opt-out or negative parental consent, that is children would participate unless their parents had chosen for them to opt them out. In 2009, children would be assessed only if their parent/guardian gave positive consent for their child's participation. Therefore, it is difficult to compare the findings of the two surveys. In addition, there are some suggestions that surveys that require positive consent may underestimate diseases' levels in a population, as consent from parents/guardians of children who are more deprived is less likely to be granted.

For children who had some experience of decay, data for 2009 indicated that those that lived in the most deprived neighbourhoods had on average 3.3 teeth affected by decay, compared to 2.9 affected teeth in those resident in the least deprived areas (Witton & Nelder, 2009). In 2000, the corresponding figures were 4.2 and 3.1 affected teeth. Furthermore, the greatest fall in the prevalence of children affected by decay from 2000 to 2009 was observed in the least deprived groups. These findings indicate that health inequalities exist between the least and most deprived children living in the city.

Data from the National Dental Epidemiology Programme showed that in 2012, the caries levels among five year old children in Plymouth were lower than the average for England (Public Health England, 2014). More specifically, 24.9% of children in Plymouth who took part in the survey were affected by dental caries, compared to an average of 27.9% for England, while the number of teeth that were decayed, missing or restored was on average 2.63 in Plymouth, compared to the national average of 3.38. Children in Plymouth were also found to have lower d₃mft compared to the average for England (0.65 as compared to 0.94). Better outcomes for Plymouth children compared to the average in England were also observed in the latest survey of the National Dental Epidemiology Programme of five year olds that was conducted in 2015 (Public Health

England, 2016b). Furthermore, compared with the local findings in 2012, it is evident that improvements were observed in the mean d₃mft and percentage of children in Plymouth affected by decay (0.4 in 2015 compared to 0.65 in 2012 and 15.3% as compared to 24.9% in 2012), even though an increase in the average d₃mft was found in the children affected by decay (2.8 in 2015 compared to 2.63 in 2012).

2.2.3 Caries Aetiology

Dental caries is considered by many to be a multifactorial disease (Cameron & Widmer, 2008; FDI World Dental Federation, 2015; Gupta et al., 2013; Hunter, 1988). The origin and development of the condition depends on a variety of factors, including microbial, genetic, behavioural, pathological, environmental and lifestyle related factors (Selwitz, Ismail & Pitts, 2007; Struzycka, 2014; van Houte, 1994). Thus, the status of dental caries can be considered as a balance between protective factors, risk factors and pathological factors (Struzycka, 2014). When demineralisation is more rapid than remineralisation, caries is the outcome (Begzati et al., 2015). However, the evidence suggests that environmental factors, particularly a high refined carbohydrate diet and oral hygiene, are the main determinants of the disease (van Houte, 1994).

Understanding how these factors operate to contribute to the pathogenesis, progression and prevention of caries is paramount to developing effective strategies and programs.

2.2.4 Risk factors

2.2.4.1 Microbial aetiology

Several studies have identified bacteria that are implicated in the outset and development of dental caries. The main group of bacteria known to be involved in the caries disease process includes *Streptococcus mutans* and *lactobacilli* (Colak et al., 2013; Touger-Decker & van Loveren, 2003). *Streptococcus mutans* is considered a major

aetiological factor of caries (Grindefjord et al., 1996) and is the main cariogenic organism among more than 500 species of bacteria that are found in the oral cavity (Paster et al., 2001). Cariogenic bacteria produce acid during the metabolism of sugars that are derived from diet, which then result in the demineralisation of the enamel and teeth (Touger-Decker & van Loveren, 2003).

It has been suggested that the bacterial profiles change in different disease stages and that they differ between primary and secondary dentition (Aas et al., 2008). In addition, bacterial species other than *S. mutans* are likely to contribute to the progression of caries (Aas et al., 2008). In a recent study which included 110 participants, a positive correlation was identified between decay, *S. mutans*, *Lactobacilli* and *Actinomyces* in the primary and secondary dentition; the authors confirmed that these bacteria are elements of the normal microbial flora of the oral cavity and contribute to the pathogenesis of dental caries and that increased number of microorganisms contribute to increased caries frequency (Chokshi et al., 2016).

2.2.4.2 Sugar consumption

High and frequent sugar consumption has long been considered an aetiological factor in caries development (FDI, 2016; Moynihan et al., 2003) and abundant evidence links consumption of free sugars¹ with caries (Sheiham & James, 2015). Sugars are considered the most important cause of caries in both children and adults (Sheiham, 2001) and are a necessary dietary factor in the development of the condition (FDI, 2016). In parallel, Marshall et al. (2003) supported that dietary modifications, and in particular an increased consumption of soft drinks (often containing high sugar content) can contribute to worse caries outcomes in children.

¹ **Definition of free sugars (PHE, 2015, p.10):** ‘Free sugars are those added to food or those naturally present in honey, syrups and unsweetened fruit juices, but exclude lactose in milk and milk products. The free sugars definition is used by the WHO and does not include the figure of 50% of sugars in dried and cooked fruit’.

In Japan, a very strong relationship was found between the DMFT of 12 year old children and the per capita consumption of sugar per year between 1957 and 1987. In particular, an increase in the mean DMFT of 12 year olds from 1957 to 1975 was found to correlate with the increase in sugar intake that followed the Second World War (Miyazaki & Morimoto, 1996). Similar findings were shown recently in Kenya, where dental caries experience in the country increased in parallel with an increase in the per capita consumption of sugar (Macigo et al., 2016). Per capita sugar consumption between 1969 and 2009 increased by nearly twofold (from 35.5g/day to 60.8g/day, respectively) while dental caries in primary (in 3- 5 years old) and permanent dentition (at 12 years of age) increased from 1.5 dmft/dt in 1980 to 2.95 in 2000s and from 0.2 DMFT to 0.92 in the same period, respectively. Recent evidence from cross-sectional and longitudinal studies also supports the significant impact of sugar on caries (Chi et al., 2015; Punitha et al., 2015).

A birth cohort study of children and adolescents aged between 6 and 18 years which examined whether feeding practices related to sugar intake affect dental caries, showed that the higher the sugar consumption was over the life course, the higher the increase in dental caries experience (Peres et al., 2016). In this study, even a low consumption of sugar was found to relate to caries. In a longitudinal study of 510 three year old children, it was shown that children were 2.99 times more likely to suffer from higher caries increment when they consumed 32.6g of sugar on a daily basis at nursery compared to those who consumed less than this amount (Rodrigues & Sheiham, 2000).

A strong link between consumption of SSB and caries has been shown in several studies. A study which analysed data on 3,194 American youth that took part in NHANES (1971-1974), found a significant positive relationship between soft drink consumption (during and between meals) and dental caries and the relationships

remained significant even after adjusting for other confounding factors including other sugary foods (Ismail, Burt & Eklund, 1984). Furthermore, in 642 children of the Iowa Fluoride Study (Marshall et al., 2003), consumption of regular soda pop also positively related to dental caries risk. In a cross-sectional study of 16,508 Australian children from 5 to 16 years of age, greater consumption of sugar sweetened beverages (SSB) was found to be significantly related to dental caries even after controlling for confounders (Armfield et al., 2013).

Yet, SSB continue to be the main source of sugar in children's diets (Keller & Bucher Della Torre, 2015). Analysis of data from a representative sample in the US aged two and older (N=15,010), found that soft drinks contributed to the highest amount of sugar in children's diet (Guthrie & Morton, 2000). Consumption of soft drinks was also high in a cluster sample of 418 English children from Birmingham city aged 14 years old; more than 80% of these teenagers regularly consumed soft drinks (Al-Dlaigan, Shaw & Smith, 2001).

A recent in-depth systematic review which examined the impact of restricting sugar consumption on caries, indicated that there is consistent moderate quality evidence supporting an association between sugar consumption and caries development (Moynihan & Kelly, 2014); the same review specified that caries experience is lower when free-sugars contribute to less than 10% to the total energy intake. The findings were confirmed by another in-depth systematic review which showed that moderate-quality evidence exists showing that sugar affects caries development and that the burden of the condition is lower when consumption of free sugars does not exceed 10% of energy (Freeman, 2014).

The National Diet and Nutrition Survey (2012/2013–2013/2014) in the UK, showed that average consumption of non-milk extrinsic sugars (NMES)² in children was beyond the Dietary Reference Values (DRV) of providing no more than 11% of food energy. In children aged 1.5 to 3 years, intake was 12.2%, in 4 to 10 year olds it was 13.4% while in older children, aged 11 to 18 years, it was 15.2% (Public Health England, 2016). Taking into account the new guideline adopted by the UK government in July 2015 (Public Health England, 2015a), advising that free sugar average consumption should not provide more than 5% of the total energy intake in individuals aged two years and above³, the data from the NDNS show that this recommendation is significantly exceeded in the diet of English children.

A dietary habit which has been shown to influence caries development through increased sugar intake, is missing/skipping meals, as this can affect snacking during the day and can result in an increased consumption of sugary items. In a study which analysed data on 4,236 children that took part in the Third NHANES, it was shown that skipping breakfast was associated with overall caries experience and untreated decay in the primary teeth in children aged two to five years (Dye et al., 2004). Furthermore, in a cohort of 162 girls that were followed for a three-year period, skipping breakfast and having meals at inconsistent times were shown to significantly affect augmentation of caries in this population (Bruno-Ambrosius, Swanholm & Twetman, 2005). However, others were not able to establish a link between this dietary habit and caries (Punitha et

² **Definition of NMES provided by PHE (2015, p.10) and used by national surveys in the UK:** ‘NMES are defined as sugars in unsweetened fruit juice and honey, as well as sugars that are added to food and drink. They also include 50% of the weight of sugars found in dried, stewed or canned fruit. Sugars naturally occurring in milk or milk products are excluded.’

³ In 2015, the Scientific Advisory Committee on Nutrition (SACN) (2015) proposed that the UK adopted the definition of ‘free sugars’ in place of ‘NMES’.

al., 2015). Snacking in between meals has frequently been also cited as a significant predictor of caries in children (Prakash et al., 2012).

2.2.4.3 Poor oral hygiene

Dental caries experience is known to be worse in children with poor oral hygiene. A systematic review of risk factors for childhood dental caries indicated that the balance between oral hygiene habits and consumption of sugar is important in caries development (Harris et al., 2004). In a cross sectional study which involved Mexican children four to five years of age, dental caries experience was significantly associated with poor oral hygiene (Molina-Frechero et al., 2015). In 362 Cambodian children of pre-school age, tooth brushing related to dental caries experience and lack of tooth brushing was one of the most prominent risk factors for ECC in this population (Turton et al., 2016).

2.2.4.3.1 Fluoride as a caries inhibiting factor

Despite overwhelming evidence linking dental caries with sugar consumption (Sheiham & James, 2015), a systematic review reported that in modern times, the role of sugar consumption in the development of caries has weakened significantly due to fluoride measures that are being implemented (Burt & Pai, 2001). The authors emphasised that intake of sugar should remain part of preventive programs targeting caries but should not be the most important aspect. This view has further been supported in a recent review which argued that sugar per se is not the only determinant of dental caries (Gupta et al., 2013).

The beneficial impact of fluoride (mainly through its topical effect) on caries is well documented (Alm, 2008) while tooth brushing is the most common method of applying fluoride (Ellwood & Fejerskov, 2003; Miller et al., 2012; Twetman, 2009); it is most effective (tooth brushing) when it is applied twice a day (Sheiham, 1979). Apart from

tooth brushing, water fluoridation is another way of protecting the population from dental caries (Do, Ha & Spencer, 2015; Levy et al., 2003). Fluoride is believed to have contributed to the significant reduction in caries levels in the last decades (Nyvad, Machiulskiene & Baelum, 2003; Petersen, 2010; Rugg-Gunn, 2013; Splieth, Christiansen & Foster Page, 2016).

The positive impact of fluoride has been demonstrated in many studies and systematic reviews of evidence. In 12-year old children, fluoride was found to be related with 25% lower caries experience when sugar intake was constant at between 10-15% of total energy intake (Marthaler, 2004). Tooth brushing frequency also related to the incidence of ECC in 96 African-American children between the ages of 3 to 22 months where greater tooth brushing frequency reduced the incidence of dental caries by 0.34 OR ($p=0.01$) (Ghazal et al., 2015). In another study involving 2,611 children between 8 to 12 years of age from the state of New South Wales in Australia, significant associations were found between caries prevalence and severity and exposure to fluoride in early years of life. In children who were exposed to fluoridated water during the first three years of their life, the burden of caries at 8 to 12 years was lower (Do et al., 2014). Fluoride intake from diet has also been shown to be inversely associated with the prevalence of caries in five year old Korean children (167 boys and 147 girls) (Kim et al., 2015). The decayed or filled surfaces of the children were shown to be significantly higher in children with a lower intake of dietary fluoride.

Several RCTs have also demonstrated the beneficial effect of fluoride toothpastes on the oral health of children (Davies et al., 2002; Newby et al., 2013; Pieper et al., 2016; Schwarz, Lo & Wong, 1998). For example, in their trial on 2,228 children aged two to four years, Pieper et al. (2016) showed that a preventive program in kindergarten involving daily tooth brushing under supervision, resulted in 24% lower caries

increment in the group that received the intervention compared to the control group ($p=0.04$) which was given tooth brushing instructions three to four times a year.

An updated systematic review demonstrated moderate evidence that fluoride gel has a caries inhibiting effect on the permanent teeth. Although some evidence has shown a protective impact of fluoride in the primary dentition this comes from low quality studies (Richards, 2015). A recent systematic review of papers published between 1948 to 2014 also indicated that application of fluoride can remineralise and arrest caries in children (Gao et al., 2016), while a review of RCTs in children less than seven years of age concluded that standard fluoride toothpastes are effective to reduce caries in preschool children (Elkhadem & Wanees, 2014).

Gibson and Williams (1999) examined the association between caries and consumption of sugars in 1,450 pre-school English children. They showed that the amount and frequency of sugar confectionary was associated with caries only in those children with a tooth brushing frequency of less than two times a day (Gibson & Williams, 1999). Thus, although sugar consumption is considered an important determinant of caries development, several authors support that it is not the only factor determining the development of dental caries. This view was supported by a study of 125 mentally disabled and 79 healthy 9 to 10 year old children from Finland, where poor oral hygiene practices were the most important determinant of caries risk (Palin-Palokas, Hausen & Heinonen, 1987).

In a recent review, Sheiham and James (2015) argued that the importance of sugars is underestimated and not given proper attention in prevention strategies. They also suggested that caries inhibiting factors such as fluoride and dental hygiene would not be needed if we addressed the single cause which is sugars. Their arguments find support in the recent statement of FDI (2016), which acknowledges that although other factors

including use of fluoride influence the development of dental caries, they cannot be considered as aetiological.

2.2.4.4 Feeding practices

The effects of feeding practices on caries development during the early years of life, particularly the effects of bottle feeding and breastfeeding, have been examined in several studies.

A study of 302 children aged 6 to 71 months from Lagos, showed that there were significantly higher ECC in children that were bottle-fed at night (Olatosi et al., 2015). Feeding practices, particularly bottle-feeding, resulted in higher prevalence of caries and ECC in 400 children aged three to five years in Syria (Qadri, Nourallah & Splieth, 2012). In particular, children who were bottle-fed had significantly higher prevalence and severity of ECC compared with breastfed children ($p=0.036$). Furthermore, in bottle fed children the mean DMFT was 5.33 ± 4.6 while in children who were mainly breastfed the corresponding number was 3.27 ± 3.5 (Qadri, Nourallah & Splieth, 2012). Bottle-feeding during night time, as well as sleeping with the bottle in the mouth, were identified as caries risk factors in another study of children aged 9 to 18 months in Thailand (Detsomboonrat & Pisarnurakit, 2015).

The relationship between use of a bottle and caries is even more evident when the liquid consumed is something other than milk, such as fruit juice; this could be due to the acidity of these beverages, their sugar content as well as frequent use of the bottle (Colak et al., 2013; Feldens et al., 2010). A birth cohort study, which investigated the role of early feeding practices and the development of severe ECC later in childhood in 340 children in South Brazil, showed that amongst several practices, the ingestion of liquids other than milk with a bottle resulted in a significantly higher adjusted risk of S-EEC (RR=1.41; 95% CI: 1.08-1.86).

The WHO guidelines recommend that infants should be exclusively breastfed until six months old and after that breastfeeding should accompany the introduction of solid foods up to two years of age or beyond (WHO, 1998) because of the various benefits this practice provides for the developing child. Despite the fact that it is suggested that frequent and extended contact of human milk with the teeth contributes to an acidogenic environment and softening of the enamel (Colak et al., 2013; Feldens et al., 2010) a recent systematic review and meta-analysis (Avila et al., 2015) which examined the relationship between feeding practices (breastfeeding vs bottle feeding) and dental caries in childhood gave support to the WHO recommendations described above. The review showed that breastfeeding can actually protect against dental caries in childhood and meta-analyses of evidence from cross-sectional studies indicated that children who breastfed were less affected by dental caries compared to children who were bottle-fed (OR=0.43; 95% CI: 0.23-0.80). This was supported by another systematic review which showed that children who breastfed for more than 12 months had less caries compared to those who breastfed for a shorter duration (Tham et al., 2015).

2.2.4.5 Sociodemographic factors

Several sociodemographic factors have also been shown to influence the development of dental caries including age, gender and ethnicity. It also appears that obesity and dental caries share similar socioeconomic factors that affect their development.

2.2.4.5.1 Age

Detailed data from the Ten-State Nutrition Survey (TSNS) of 1968-1970 which included more than 10,000 participants aged 5 to 20 years, indicated that caries is an 'age-site dependent' condition with different classes of teeth being affected at different ages and at different rates (Rowe et al., 1976). Evidence from this study showed that

dental caries begins soon after teeth erupt, increases up to late adolescence and then stabilises during the third decade of life (Rowe et al., 1976).

Several more recent studies have provided evidence into the impact of age on the condition, albeit not as detailed as the above study and being limited by a cross-sectional design. For example, in a sample of two to five year old children, dental caries experience was shown to increase with age (Dye et al., 2004). In Arizona preschool children, the prevalence of caries (and mean dmft) was 6.4% (mean dmft=0.18), 20% (mean dmft=0.70) 35% (mean dmft=1.35) and 49% (dmft=2.36) at the age of one, two, three, and four years, respectively (Tang et al., 1997). Also, in a sample of 519 schoolchildren in Venda, South Africa (Bajomo, Rudolph & Ogunbodede, 2004), although the mean dmft in six year old children was higher compared to the older children, the mean DMFT in 15 year olds was twice as high compared to the 12 years old [(0.61-SD 1.50) and 1.26 (2.18), respectively]. Evidence on 2,052 children out of which 1,088 were identified with caries, indicated a positive relationship between caries prevalence and age, with the prevalence of caries increasing with age (Shang et al., 2008).

However cross-sectional data on the effect of increasing age on caries are not consistent, as some studies have not found significant differences in the prevalence or severity of the condition by different age groups (Liu et al., 2013; Sgan-Cohen et al., 2014) while others have shown that younger children have higher caries prevalence or severity as compared to their older peers (Sgan-Cohen et al., 2014).

2.2.4.5.2 Gender

Several studies have revealed a gender difference in dental caries experience, with females being more profoundly affected than males (Lukacs, 2011), however, the evidence is not consistent (Rowe et al., 1976).

For example, in a cluster sample of children aged 7 to 9 years in Dalian severity of caries was higher in girls compared to boys (Liu et al., 2013). Similarly, in 791 Libyan children aged 12 years old dental caries was more prevalent in females (Huew et al., 2011). However, no differences by gender were observed in a study of 355 children aged 12 years from Northwest Russia (Gorbatova et al., 2012) and in a sample of 12 year old Polish children (Rodakowska et al., 2013). In contrast, a cross-sectional study of 993 children aged two to six years showed that boys were more profoundly affected by the severity of dental caries (Carino, Shinada & Kawaguchi, 2003) while in Southern Italy among children 10 to 11 years of age registered at the 5th grade of the only public school in a small area, the boys had more severe caries compared to girls (mean DFT: 3.20 vs a mean DFT of 1.96 in girls) (Migale et al., 2009).

The greater caries experience of females seen in some studies may be explained by the earlier tooth eruption in girls which means that teeth are longer exposed to cariogenic conditions, as well as their dietary preferences (Ferraro & Vieira, 2010; Lukacs & Largaespada, 2006; Rowe et al., 1976). In the South Asia region, the gender differences appear to result from genetic, hormonal and cultural factors (Lukacs, 2011). With regard to older women, the higher prevalence of dental caries could be explained by the easier access to food and frequent snacking while cooking (Lukacs & Largaespada, 2006).

2.2.4.5.3 Ethnicity/Race

Ethnicity/race has been found to be an important determinant of oral health inequalities in children, with children from white backgrounds consistently found to have better caries outcomes as compared to their peers from other ethnic/racial groups (Drummond et al., 2015; Wu et al., 2011).

Data from the Ten-State Nutrition Survey of 1968-1970, referred to earlier, showed a consistent and large difference in caries experience between black and white children,

with caries incidence being higher in black than white children of the same ages (Rowe et al., 1976). Other analyses also indicated that caries experience was higher in Mexican-American children (39.7%), compared to Hispanic black (28.6%) and non-Hispanic white children (18.1%) (Dye et al., 2004). Furthermore, children with greater untreated decay were more likely to be Mexican-American (Dye et al., 2004). Among 2,520 Californian preschool aged children, the risk of ECC was approximately three times higher in Asian than in white children (Shiboski et al., 2003). A significant positive association was also found between minority ethnicity/race and caries patterns in Arizona children aged 5 to 59 months old (Psoter et al., 2006), while a cross sectional study of 181 dyads consisting of parents/guardians and children/wards aged three to five years who took part in the Head Start Program in California, showed that children whose parents/guardian were Hispanic had the highest rates of severe ECC (Weatherwax et al., 2015).

A recent study that analysed data from the 2010 National Oral Health Survey in Brazil (Drummond et al., 2015) indicated that the significant reduction in caries experience observed among adolescents (15 -19 years old), was more obvious in individuals of white background than in those of African descent and those of mixed race. The authors highlighted that education and income significantly affected the comparison results.

Thus, despite evidence showing the impact of ethnicity/race on caries, whether this is a result of ethnicity/race per se or other confounders which also affect dental caries (i.e. SES) has not yet been elucidated (Drummond et al., 2015). Relatively recent data from the National Survey of Children's Health in the US suggest that racial/ethnic differences in children's dental health are due to economic and social factors (Guarnizo-Herreno & Wehby, 2012).

2.2.4.5.4 Low SES

The link between socioeconomic status and oral health is widely acknowledged (Locker, 2000). Several studies of cross-sectional and longitudinal design provide evidence for the presence of inequalities in children's dental caries experience, with children from lower-SES being more profoundly affected in terms of prevalence and severity of the condition (Peng et al., 2014a; Public Health England, 2016b; Santamaria et al., 2015; Sweeney, Nugent & Pitts, 1999). Children from lower SES have also been shown to have significantly higher treatment needs compared to their affluent peers (Irigoyen, Maupome & Mejia, 1999).

Analysis of data on 2,871 German children showed that dental caries were significantly higher in schools who had children from lower SES (Santamaria et al., 2015). Furthermore, in a cohort of 2,303 children in Sweden aged 10 years with data on SES at 4, 5, 7 and 10 years of age, SES was found to have a negative association with caries prevalence at all ages (Gerdin et al., 2008). A systematic review indicated that there was fairly strong evidence showing an inverse association between SES and the prevalence of the condition, especially for children less than twelve years of age (Reisine & Psoter, 2001). The impact of SES status on dental caries in children has been recently confirmed by another systematic review of evidence which indicated that 6 to 12 year old children from lower SES classes had higher dental caries experience in their permanent dentition (Kumar et al., 2016).

Evidence also links caries experience with other aspects of deprivation. For example, in a sample of 12,706 children in Denmark (5-15 years old), multiple regression analysis indicated that the children with the highest levels of caries were those belonging to families whose mothers were not Danish and had low educational level, as well as low income (Christensen, Twetman & Sundby, 2010). Mother's educational level has been

shown to have a strong link to children caries experience in a number of studies (Al Agili & Alaki, 2014; Carta et al., 2014; Sankeshwari et al., 2013).

Behaviours that affect the oral health of disadvantaged individuals include poor oral health habits, limited use of dental services and unhealthy dietary habits such as consumption of sugary foods and beverages (Chen, 1995). High consumption of fruit juices and soft drinks as well as low intake of calcium have also been shown to determine risk of caries in children at low SES schools (Jerkovic et al., 2009). Price also determines the food choice of individuals (Darmon & Drewnowski, 2008; Darmon et al., 2014; Epstein et al., 2007) and taking into consideration that energy dense foods (which tend to be of higher sugar and fat content) are of lower cost, it is not surprising that people with less disposable income tend to consume such food more frequently.

Chen (1995) has provided an extensive review into the characteristics of people from lower SES and how these affect their greater vulnerability to dental caries. He (Chen, 1995) reported on the characteristics and behaviours that impact the oral health of people from lower SES and suggested that all factors at the individual level interact, not only with each other, but also with the dental healthcare system, the broader environment, the culture and the environment to influence oral health. Individual characteristics of people from lower SES reported by Chen (1995, p.186), include ‘fatalistic health beliefs, pessimistic attitudes, lack of knowledge, placement of low value on oral health, low perceived susceptibility to oral diseases, low perceived seriousness of dental problems, high perceived barriers to oral health behaviour, and low perceived benefit of oral health behaviour’.

As Locker (2000) has previously pointed out, further to the evidence demonstrating the clear link between deprivation and oral health, there is a need to identify factors that create and maintain oral health inequalities.

2.2.4.6 Genetics

With regard to the genetic factors that affect dental caries, it has been shown that saliva, particularly its composition and flow rate, can have a major effect on the development of the condition (Struzycka, 2014; van Houte, 1994). Other genetic factors such as tooth morphology, enamel and dentine formation as well as time of tooth eruption are also considered important in the development of dental caries (Wang et al., 2012). Various genes that affect enamel development, saliva function as well as immune response are also believed to affect susceptibility of an individual to caries (Vieira, 2012).

The role of genes in childhood dental caries has been strongly supported by twin studies which examined the heritability of the condition (Liu et al., 1998) and several other studies in families. The first genome analysis for caries was conducted in 46 families that lived in the Philippines and had similar cultural and lifestyle habits (Vieira, Marazita & Goldstein-McHenry, 2008). The investigators examined 392 markers and found that three genes related to low susceptibility to caries (5q13.3, 14q11.2, and Xq27.1) while two increased to high susceptibility to the condition (13q31.1 and 14q24.3). They also emphasised that flow of saliva and eating habits may be partly genetically determined.

As part of the Iowa Fluoride Study, several genetic and environmental components that may relate to caries were analysed in 575 unrelated children with a mean age of 5.2 years (Wang et al., 2012). In terms of genetic factors, single nucleotide polymorphisms (SNP) in seven potential genes were examined; SNPs that were located in the genes DSPP, KLK4 and AQP5 were found to exert protective effect against caries; the KLK4 gene was also found to have a pivotal role in the mineralisation of enamel in another study (Lu et al., 2008). The results overall supported the notion that genes can influence a child's susceptibility to caries (Wang et al., 2012).

Genetic factors that affect caries may differ by dentition, and thus susceptibility to the condition may be affected by different genes at different times. In a heritability study on adults and children from 740 families, it was shown that caries related phenotypes in the deciduous teeth accounted for more than 50% variation in caries scores, while in the permanent dentition the heritability of caries scores was lower (35-55%) (Wang et al, 2010). This suggested that it would be better if genetic elements of dental caries in the two dentitions were studied separately (Wang et al., 2012).

Another study examined genetic influences on the dentitions of 44 pairs of twins reared apart with a mean age of 40.6 years (SD=11.7) (Boraas, Messer & Till, 1988); the participants underwent examinations over a six-year period. Although, the number of teeth, the percentage of restored teeth and surfaces and the tooth size and malalignment were significantly similar within the monozygotic (MZ) pairs, this was not the case for dizygotic (DZ) pairs. Morphological features were also more consistent in MZ rather than DZ twins. The study provided new information of genetic influence on dental characteristics and caries and confirmed the results of other studies indicating inheritance in tooth characteristics.

Goodman et al. (1959) examined heritability in caries, oral microflora and saliva elements in 38 like-sexed twin pairs (19 monozygotic, 19 dizygotic) aged between 14 to 38 years. They found that the mean intra-pair variances of caries experience ratio in DZ twins was higher than those of MZ twins whether in relation to the whole mouth or the dentition. In addition, variance ratios that were calculated for rate of flow, pH, and amylase activity of parotid saliva and a mixture of sublingual and submaxillary (S&S) saliva specimens indicated that there was a significant heritability and therefore genetic influence on these variables. The only exception was for the pH of S & S saliva.

The authors attributed the lack of evidence of heritability in these variables to technical difficulties.

In another study, Horowitz, Osborne and DeGeorge (1958), showed that caries experience within MZ twins was more similar than that identified within the DZ twins. This was similar to the findings of Mansbridge (1959) who found that in 232 like-sex twin pairs, the resemblance in caries experience was greater in MZ compared to DZ twins. However, this was not the case in an earlier study which found no differences between MZ and DZ twins (Bachrach & Young, 1927).

Taking into account the evidence presented above, dental caries aetiology seems to involve an interaction between environmental and genetic factors (Hunter, 1988).

2.2.4.7 Family and Community-level factors

In addition to the environment within the oral cavity and individual level factors that can determine an individual's experience to dental caries, there are also external influences which affect the development of the condition. The Oral Health Atlas (FDI 2015) provides a list of those factors that act over time to influence the development of the condition and include factors at the family and community level (e.g. culture, physical safety, social support, family function at the family level and social capital, physical environment, characteristics of the healthcare and dental care system and community oral health environment at the level of community). Such factors can affect the behaviours individuals adopt which are then shaped by wider influences such as policies, education and politics (FDI 2015; WHO 2008).

2.2.5 Consequences of dental caries

Oral diseases can have a detrimental effect on a person's health both, in childhood and in later life and on the society overall (FDI World Dental Federation, 2015; Petersen et al., 2005). The Global Burden of Disease Study in 1990-2010 indicated that within this

time period the oral disease related Disability-Adjusted Life-Years [(‘DALYs: the years of life lost due to premature mortality and years lived with disability’, (Murray et al., 2012, p.2199)] increased by 20.8% and taken together oral conditions were responsible for 15 million DALYs globally (Marcenes et al., 2013). Between 1999 and 2010, DALYs due to untreated caries rose by 5.3% and 38.1% in primary and secondary dentition, respectively, mainly because of population growth and aging (Marcenes et al., 2013).

Early childhood caries in particular, can have both immediate and long-term consequences on a child’s (and their family’s) quality of life and can adversely affect the economy as well; unless targeted at its early stages, tooth decay becomes irreversible (Colak et al., 2013; The California Society of Pediatric Dentistry and California Dental Association, 2014).

2.2.5.1 Quality of life

Dental caries can have a negative impact on a child’s quality of life (Colak et al., 2013; Scarpelli et al., 2013), while the stage of progression and type of tooth affected can determine the power of the impact (Guedes et al., 2016; Li et al., 2015b; Ramos-Jorge et al., 2015). A child may suffer from pain and discomfort caused by the condition, which can cause further infections and alter children’s daily habits (Colak et al., 2013). As a result of toothache or the need for treatment of dental decay, children may also need to miss school and their parents may need to take leave from work (Royal College of Surgeons: Faculty of Dental Surgery, 2015).

Indeed, when untreated and severe, tooth decay can also subsequently reduce the child’s ability to have a healthy and varied diet; it can also lead to problems with speaking and playing as well as sleep (CDC, 2014; The California Society of Pediatric Dentistry and California Dental Association, 2014). Severe caries may thus restrict activities at school

and at home, and can cause problems with smiling and communicating with others (Petersen et al., 2005). Early childhood caries may also affect children's school performance and behaviour (Casamassimo et al., 2009).

In a study that included 500 child-parent pairs aged three and six years, children with ECC had significantly lower oral health-related quality of life (OHRQOL) parameters including sleeping and eating, when compared to their peers who were caries-free (Acharya & Tandon, 2011). Another study, which examined the impact of oral pain on eight year old Sri Lankan children, showed that caries was the most common reason for oral pain in children, and this had a negative impact both on the child and their parents (Ratnayake & Ekanayake, 2005). It should be noted that the severity of ECC was found to be directly related to the magnitude of the impact on OHRQOL, while high household income was shown to have a protective effect (Abanto et al., 2011). Low family income as well as untreated caries were found to have a significant adverse effect on OHRQoL in a more recent study involving 1204 Brazilian children aged 8 to 10 years (Martins et al., 2015). Also, the treatment of severe caries under general anesthesia had an immediate positive impact on children's (and their family's) OHRQoL (Ridell et al., 2015).

2.2.5.2 Aesthetics

Aesthetic issues related to the presence of decay can affect children's self-esteem and their relationship with others (The California Society of Pediatric Dentistry and California Dental Association, 2014). A significant effect of caries is the loss of a tooth because of the need to perform an early extraction of the affected tooth. This can affect children's speech, cause abnormalities in the eruption of teeth and as a result an orthodontic problem (Begzati et al., 2015). In addition, premature tooth loss due to severe tooth decay and subsequent need for extraction can also adversely affect the

alignment of permanent teeth (Law, 2013). Teeth damaged by caries may need restoration and maintenance throughout life (Selwitz, Ismail & Pitts, 2007).

2.2.5.3 Growth

Early childhood caries can also affect children's growth. Acs et al. (1992), showed that children with nursing caries had a lower weight than their matched controlled peers, and that they were significantly more likely to weigh less than 80% of their ideal body weight; the latter comprised of 8.7% as compared to only 1.7% in the matched group. The authors concluded that severe nursing caries may adversely affect children's growth. Furthermore, a review showed that dental caries in children who are otherwise healthy, can contribute to failure to thrive (FTT) (Elice & Fields, 1990). In a cross sectional study on 285 Peruvian children aged 3 to 9 years, caries prevalence was higher in children with chronic malnutrition and stunted growth indicating a possible relationship between caries and FTT (Alvarez et al., 1988).

Several recent studies from China, Saudi Arabia and the Philippines also show that caries experience is negatively related to anthropometric outcomes associated with growth (Alkarimi et al., 2014; Benzian et al., 2011; Yang et al., 2015). AlKarimi et al. (2014), for example, showed in their analysis on 417 children aged six to eight years that their weight, height and BMI negatively related to caries. Even after adjusting for potential confounders, each consecutive group with higher caries levels had significantly lower anthropometric outcomes. Moreover, in a cross-sectional study of 744 children aged eight years from China, those who were underweight were shown to have the most severe caries indicating that the condition can negatively impact on growth and development of children (Yang et al., 2015).

The association of caries with growth is also evident through studies showing that dental treatment of children with early childhood caries or severe decay resulted in greater weight gain (Acs et al., 1992; Acs et al., 1999; Duijster et al., 2013).

2.2.5.4 Persistence into adolescence/adulthood

Adding to the above mentioned consequences, children with early caries lesions have an increased probability of developing further caries in both their primary and permanent dentition (American Academy of Pediatric Dentistry, 2008; Colak et al., 2013). It has been hypothesised that this may be due to severe damage to the primary dentition. Such damage is said to harm the enamel of the secondary teeth during development prior to their eruption into the mouth (The Royal College of Surgeons, 2015); however, the damage to the primary teeth would have to occur earlier in the child's life for this to be the case.

A study examining the relationship between early caries with subsequent incidence in preschool life showed that existence of caries at age three to four years, can predict the children who will be at higher risk for developing caries in the future (O'Sullivan & Tinanoff, 1996). Furthermore, a cohort study with eight years of follow-up suggested that caries in primary teeth of preschool children predicted the condition in their permanent dentition (Li & Wang, 2002). Johnsen et al. (1986) showed that children with nursing caries are more prone to future lesions of approximal surfaces of molars when compared to children who initially are caries-free. A recent study in Germany also indicated that severe caries in early life can lead to worse caries outcomes in adult life (mean: 14.8 DMFS; $p=0.001$).

In terms of the importance of childhood caries into adolescence and adult life, a prospective cohort study of 1,037 individuals from New Zealand showed that childhood caries continued into adulthood (Broadbent et al., 2013). The persistence of caries into

later life was also confirmed in a systematic review which indicated that future development of the condition was significantly predicted by caries experience in the past (Powell, 1998).

2.2.5.5 Economic burden

Apart from the negative impact on children and their parents, poor oral health has an economic burden on the healthcare services as well. The treatment of oral diseases is very costly (WHO, 2003b) and is considered to be the fourth most expensive disease treated in many industrialised countries (Petersen et al., 2005). Many children may require comprehensive dental treatment under general anesthesia. In the US it has been estimated that under Medicaid expenditures (a healthcare programme for families and individuals with limited resources) such interventions may cost between \$1,500 to 6,000 per child (Tinanoff & Reisine, 2009).

In addition to treatment, dental caries are also responsible for indirect costs to the economy. For example, employees requiring absence from work as a result of dental disease will cause reduced productivity (Listl et al., 2015). Direct treatment costs of oral diseases worldwide have been recently estimated at \$298 billion per year and indirect costs at \$144 billion per year (Listl et al., 2015). Acknowledging the limitations of the available data and methodologies, the authors reported that based on their findings the global economic impact of dental diseases in 2010 was \$442 billion. In the EU the annual cost for dental care amounts up to approximately 79 billion euro, while if current trends continue the cost could increase up to 93 billion Euro in 2020 (Patel, 2012).

In England, the NHS reportedly spends £3.4 billion per year on dental services for children and adults (NHS England, 2014). Yet, the NHS struggles to fill the estimated funding gap of £30 billion for 2021/2022 (NHS England, 2014). The significance of the NHS in children's dental care is evident from the fact that 7 out of 10 children in

England are cared for by a dentist within the NHS, with a projected cost of 33.4 million annually (Claxton, Taylor & Kay, 2016; Health and Social Care Information Centre 2013). For the time period 2012-2013, the cost for the NHS for tooth extractions for children aged 18 and under was £30 million (Department of Health, 2013).

The potential cost savings that an improvement in the population's oral health could have was recently examined. The model employed aimed to calculate the amount of money that could be saved if tooth decay in the UK'S 12-year old children was reduced by 25%. The results estimated that up to £8.2 million could be saved each year if 12-year old children reduced their caries rate by 25% (Claxton, Taylor & Kay, 2016).

2.2.6 Caries – Traditional Diagnostic methods

There are various methods available for the diagnosis of carious lesions. The primary and most common method of caries diagnosis is a visual examination of teeth through clinical inspection, and the use of mouth mirrors, good natural light or an artificial one (Neuhaus et al., 2009); this is also the most common method of diagnosing caries in the research setting. Despite its simplicity, a major disadvantage of this method is its low sensitivity in detecting non-cavitated lesions in the dentine or posterior proximal and occlusal surfaces (Zangooei Booshehry et al., 2010).

Sometimes the use of sharp probes may be employed in the diagnostic process (Bader et al., 2001). However, the use of probes has been discouraged by some researchers who suggest that in the case of a tooth that has become demineralised but has not yet cavitated, the pressure exerted through the probe could damage the tooth (Ekstrand, Qvist & Thylstrup, 1987). Furthermore, use of a probe has not been shown to improve the sensitivity or specificity of the assessment nor offer additional benefits over inspection only (Neuhaus et al., 2009).

Review of radiographs is another method used, particularly for the identification of caries between the teeth or in those that are not visible to the naked eye. Although the use of radiographs is increasingly used in the clinical setting for more sensitive caries diagnosis, their use in research is not encouraged as it is difficult to make them into a standard equipment (WHO, 1962). In addition, the use of radiographs requires staff to be sufficiently trained and experienced in order that they interpret radiographic findings correctly (Neuhaus et al., 2009). There are also concerns regarding the risks and legislation related to ionizing radiation (Neuhaus et al., 2009).

The Caries Clinical Trials workshop (Pitts & Stamm, 2004) reached a consensus that visual diagnosis is the standard method for diagnosing caries, but that additional methods should be investigated further. The workshop also concluded that bitewing radiography provides additional information on the diagnosis.

2.2.7 Assessment of caries-Diagnostic criteria

Several sets of criteria/scoring systems for assessing dental caries exist, each having its own unique characteristics, strengths and areas that need to be built upon. In all cases, the training and calibration of the examiner is particularly important. Below the main systems used in the field are described.

2.2.7.1 DMF (i.e. decayed, missing, filled)

Since the 1940's, the Decayed, Missing, Filled (DMF) index, which provides information on caries at cavity level has been the main method used to collect information on caries worldwide (Klein, Palmer & Knutson, 1938; WHO, 1987).

The DMF index can be calculated for the primary or secondary dentition represented by the lowercase and uppercase letters, respectively (dmf and DMF); the dmf/DMF index for an individual can be calculated by totalling each component separately and then adding them together as follows: $D+M+F=DMF$

Thereafter, in order to assess the index in a group of individuals, the total DMF is calculated and divided by the number of people in the group (US Department of Health and Human Services: National Institute of Dental Research (1991). This is the criterion recommended by WHO and the one most commonly used in research; under this system dental caries is considered to be a cavitated dentinal lesion (WHO, 1987; WHO, 1997a).

In 1979, the WHO announced that the goal for global oral health, was that by 2000, the mean score for caries should be less than three DMFT at 12 years of age (Brathall, 2000; Ditmyer et al., 2011). The first global map data on DMFT of 12-year old children was presented in 1969 and since then, a number of studies have been conducted providing data on caries levels and trends in different populations (Bratthall, 2000; Ditmyer et al., 2011).

The codes and descriptions using the WHO system are listed below (table 1).

Table 1. Scoring and criteria of the WHO system (WHO, 2013, p.43) - Permission to reproduce this table has been granted by WHO Permissions team (2017)

Code			Condition/status
Primary teeth	Permanent teeth		
Crown	Crown	Root	
A	0	0	Sound
B	1	1	Caries
C	2	2	Filled, with caries
D	3	3	Filled, no caries
E	4	-	Missing due to caries
-	5	-	Missing for any other reason
F	6	-	Fissure sealant
G	7	7	Fixed dental prosthesis abutment, special crown or veneer/implant
-	8	8	Unerrupted tooth (crown)/unexposed root
-	9	9	Not recorded

The DMF has long been used for comparison of caries experience in different populations and provides information on the condition's levels and trends over time, as

well as any restorative or surgical treatment related to it (Monse et al., 2010). Its main advantages are the simplicity in mastering and applying the criteria, the high inter-rater agreement rates and the possibility it gives for comparing results across various populations over time (de Souza et al., 2014).

In terms of drawbacks, DMF does not provide details on the consequences of caries that have not been restored and pulpal involvement is not recorded at all under this system; this is important since when untreated, caries can have a more damaging effect than carious lesions (Mehta & Bhalla, 2014; Monse et al., 2010). Another limitation of this index is that it does not contain codes for caries in the enamel and it is also difficult to distinguish between dentine caries that can be restored compared to those who need more extensive therapy (de Souza et al., 2014; Frencken et al., 2011).

Furthermore, the index can be misleading in the elderly who may have lost teeth for reasons other than caries, as well as in children who may have lost a tooth due to an orthodontic reason (Mehta, 2012). In addition, it cannot indicate the number of teeth that are at risk nor the treatment needs of an individual (Mehta, 2012). Although the DMF index has been used for many years in assessing dental health of different populations around the world, one of its major drawbacks is that is that it only shows the mean values of caries in a population and not the frequency distribution (Bratthall, 2000). Thus, although high risk individuals with significantly higher values of DMFT in the studied population are not excluded when assessing the population's health status, they may not be given the proper attention required based on their condition status (Mehta, 2012). In addition, decayed, missing and filled teeth are similarly weighted (Mehta, 2012), implying that the impact of tooth loss is the same as the impact of having a tooth restored or leaving it in the decayed state.

2.2.7.2 Significant Caries Index (SiC Index)

In an effort to formulate new goals for oral health by bringing notice to individuals within a population that have the highest scores of the condition rather than looking only at the mean values, the Significant Caries Index (SiC Index) was proposed (Bratthall, 2000).

The index can be calculated by ranking individuals in accordance to their DFMT score and selecting the one third that have the highest values (Bratthall, 2000).

2.2.7.3 The PUFA (i.e. pulpal involvement, ulcer due to root fragments, fistula and abscess) Index

The PUFA index was developed with the aim of obtaining information on the advanced stages of untreated decay as the indices to that date could not be used to assess the impact of caries beyond the dentine (Frencken et al., 2011; Monse et al., 2010).

The reproducibility of the index is very good, as shown by kappa values of three examiners on 50 children aged six years and 49 children aged 12 years (Monse et al., 2010) and it can be used both for deciduous and permanent teeth.

Similarly to DMFT/dmft, the PUFA/pufa score of an individual is derived by adding the main elements into a single score and the score is recorded separately for the primary (pufa) and permanent dentition (PUFA) (Monse et al., 2010). PUFA Ratio is calculated as (Monse et al., 2010, p.78):

$$\frac{\text{PUFA} + \text{pufa}}{\text{D} + \text{d}} * 100$$

D+d

The scoring and criteria of this index are presented below (table 2).

Table 2. Scoring and criteria for the PUFA system (Monse et al., 2010, p.78)

Code	Description
P/p	Pupal involvement: the opening of the pulp chamber is visible or the coronal tooth structures have been destroyed by the carious process and only roots or root fragments are left.
U/u	Ulceration due to trauma: sharp edges of a dislocated tooth with pulpal involvement or root fragments have caused traumatic ulceration of the surrounding soft tissues, e.g., tongue or buccal mucosa.
F/f	Fistula: a pus releasing sinus tract related to a tooth with pulpal involvement is present.
A/a	Abscess: a pus containing swelling related to a tooth with pulpal involvement is present.

Despite its advantages, this index is limited by its ability to record the consequences of infection resulting from caries in the teeth and surrounding tissues (Frencken et al., 2011). Furthermore, the use of 'u' code in the index can be considered another limitation as ulceration is not always a consequence of untreated decay but can be due to trauma or other causes (Praveen et al., 2015).

2.2.7.4 International Caries Detection and Assessment System (ICDAS II)

In an effort to develop and establish a common caries assessment system which would be informed by the strengths of already established systems and would address the need to understand how caries progress over time beyond the 'decayed' status only, the International Caries Detection and Assessment System was developed and updated several times (International Caries Detection and Assessment System Coordinating Committee, 2009; Pitts, 2004). The main advantages of this index are that it is validated and it can be used to assess the different stages of caries development in the enamel (Frencken et al., 2011; Ismail et al., 2007). The ICDAS codes lie between zero to six according to the severity of caries (International Caries Detection and Assessment

System Coordinating Committee, 2009). Below (table 3) are the criteria of the ICDAS

II.

Table 3. Scoring and criteria for the ICDAS II (International Caries Detection and Assessment System Coordinating Committee, 2009, p.2) - Permission to reproduce this table has been granted by one of the coordinators of the ICDAS Baltimore workshop (2017)

Code	Description
0	Sound
1	First Visuals Change in Enamel (seen only after prolonged air drying or restricted to within the confines of a pit or fissure).
2	Distinct Visual Change in Enamel.
3	Localised Enamel Breakdown (without clinical visual signs of dentinal involvement).
4	Underlying Dark Shadow from Dentine.
5	Distinct Cavity with Visible Dentine.
6	Extensive Distinct Cavity with Visible Dentine.

Despite its strengths, this score cannot be used to assess the most advance consequences of caries which can result in pulpal infection and destroy the surrounding tissue; furthermore, it does not allow for separate assessment/recording of the primary and permanent teeth and it is not easy to make comparisons with the results of the DMF index (Frencken et al., 2011).

2.2.7.5 The Caries Assessment Spectrum and Treatment (CAST) Index

The Caries Assessment Spectrum and Treatment (CAST) Index assesses caries at different stages of development (enamel, dentine and pulp) and records the teeth filled, lost or a cavity restored due to caries (Frencken et al., 2011). Thus, in addition to recording the number of affected lesions this index also enables users to obtain information on the consequences of carious lesions that have not been treated (Frencken et al., 2011). The codes as well as their descriptions are listed below (table 4).

Table 4. Scoring and criteria for the CAST Index (de Souza et al., 2014; Frencken et al., 2011, p.2)

Characteristic	Code	Description
Sound	0	No visible evidence of a distinct carious lesion is present.
Sealant	1	Pits and/or fissures are at least partially covered with a sealant material.
Restoration	2	A cavity is restored with an (in)direct restorative material.
Enamel	3	Distinct visual change in enamel only. A clear caries related discolouration is visible, with or without localised enamel breakdown.
Dentine	4	Internal caries-related discolouration in dentine. The discoloured dentine is visible through enamel which may or may not exhibit a visible localised breakdown of enamel.
	5	Distinct cavitation into dentine. The pulp chamber is intact.
Pulp	6	Involvement of the pulp chamber. Distinct cavitation reaching the pulp chamber or only root fragments are present.
Abscess/Fistula	7	A pus containing swelling or a pus releasing sinus tract related to a tooth with pulpal involvement.
Lost	8	The tooth has been removed because of dental caries.
Other	9	

One of its main strengths is that it builds on the advantages of ICDAS and PUFA (Frencken et al., 2011). The fact that it also comprises decayed, restored and missing teeth due to dental caries, provides a connection to the DMF index and allows for

comparison between surveys that have used the latter index (Frencken et al., 2013). CAST has been shown to provide similar estimates with the WHO criterion on caries prevalence in 419 Brazilian school children aged 6 to 11 years (de Souza et al., 2014).

Undoubtedly, the evaluation of caries status has improved over the years and will continue to evolve as new evidence becomes available, but data are often not comparable if different scoring systems are employed (Monse et al., 2010). Establishing a standard protocol for the assessment of caries lesions, will allow for international comparisons into the prevalence and severity of the condition, monitoring of trends over time and will help the development of oral health policies. Furthermore, assessing carious lesions across the total spectrum of the condition will enable better management strategies of the condition.

2.3 Obesity and dental caries –Nature of potential relationships

A systematic review published in 2006 which examined the evidence of an association between obesity and caries in children, adolescents and adults, concluded that insufficient evidence existed to clarify whether a relationship existed between the two conditions (Kantovitz et al., 2006).

Since then, there has been an increasing interest in the association of the two conditions and several studies have been conducted, however, evidence into the relationship remains equivocal. Both primary and secondary data analyses studies, as well as systematic reviews that have examined the relationship between obesity and caries in young people, have yielded inconclusive results. Some reports suggest that there is a positive association between tooth decay and weight status, i.e. being obese related with higher prevalence and/or severity of caries (Alswat et al., 2016; Mohammadi TM, 2012; Peng et al., 2014a; Powell et al., 2013; Trikaliotis et al., 2011; Vazquez-Nava et al., 2010; Willershausen et al., 2007; Yao et al., 2014). Others report that the association is

negative, that is being underweight is related with higher prevalence and/or severity of caries, or, that being obese is related to having better dental caries outcomes (Alkarimi et al., 2014; Bafti et al., 2015; Goodson et al., 2013; Heinrich-Weltzien et al., 2013; Koksall et al., 2011; Yang et al., 2015). There are also studies which found no significant association between the two conditions (Alves et al., 2013; Chen, 1998; de Jong-Lenters et al., 2015; Hong et al., 2008; Kopycka-Kedzierawski et al., 2008; Macek & Mitola, 2006). Systematic reviews investigating the association between obesity and caries have also produced conflicting results (Hayden et al., 2013; Hooley et al., 2012; Kantovitz et al., 2006; Li et al., 2015a; Silva et al., 2013).

2.3.1 Positive association

As mentioned above, some evidence points towards a positive relationship between weight status and caries. For example, a study by Alm et al. (2008) showed that 15 year old overweight/obese Swedish adolescents, had more approximal caries than their healthy-weight peers. More specifically, in overweight and obese adolescents with an isoBMI greater than or equal to 25 (N=64) the mean caries prevalence was 1.6 times higher than in individuals that had an isoBMI of less than 25 (N=338) (4.64 and 2.94, respectively; $p < 0.05$).

A significant positive relationship between BMI, decayed teeth and DMFT was also identified in a cross-sectional study of 463 adolescents aged 13 to 15 years in India ($r = 0.254$, $p < 0.001$ for decayed teeth and $r = 0.242$, $p < 0.001$ for DMFT) (Thippeswamy et al., 2011). Similarly, in a cross-sectional study conducted among school children in China aged 5 to 14 years, children that were overweight or obese were 1.547 times (OR=1.547; 95% CI=1.479, 1.618) and 1.908 times (OR=1.908; 95% CI=1.750, 2.079) more likely to experience caries than those who were underweight or of healthy weight

(Yao et al., 2014). The relationship between BMI categories and caries remained significant after controlling for age and gender.

A similar study in preschool children in Hong Kong showed that dental caries was positively related to obesity status when the latter was measured by weight/height ratio and waist circumference but not BMI (Peng et al., 2014a). Moreover, in 12-year old children, central and peripheral obesity, as measured by waist-to-hip ratio (WHR) and triceps skinfold, were positively associated with dental caries. In particular, it was shown through an adjusted regression analysis that a significant association existed between children's WHR z-score and a high and 'very high' experience of tooth decay (OR=1.33, 95% CI: 1.05, 1.70; p=0.02 and OR=1.52, 95% CI: 1.10, 2.11; p=0.01, respectively). Children with increased triceps skinfold z-score were 1.47 more likely to have 'very high' experience of tooth decay (OR= 1.47, 95% CI: 1.10, 1.96; p=0.01). However, no relationship was shown when BMI or weight/height ratio was used for the assessment of general obesity (Peng et al., 2014b).

2.3.2 Negative association

Other reports have shown that the association between weight status and decay is negative. For example, a study in Turkey which included 245 primary school children indicated that in underweight children the risk of developing dental caries was higher when compared to overweight/obese children ($r=-0.139$, $p=0.03$) (Koksal et al., 2011). In another study, it was found that dental decay decreased as BMI increased and this was more evident in male participants; this study involved 8,275 Kuwaiti children of both genders aged 11.36 ± 0.1 years (Goodson et al., 2013).

Finally, a recent cross-sectional study among 1,482 Iranian children aged three to six years, showed that caries rates in the primary dentition of children decreased as body weight increased (Bafti et al., 2015). More specifically, the mean dmft for children with

normal BMI, was 1.5 times higher than in children who were overweight. In the same study, age had a significant effect on dmft ($p < 0.001$), with a one year increase in age, resulting in 1.3 fold higher dmft (Bafti et al., 2015).

2.3.3 No association

The absence of an association between overweight/obesity and caries prevalence and severity was evident in several studies, including one that used secondary data from NHANES and had one of the biggest sample sizes in the field; in this study, the participants included 7,617 children and adolescents aged 2 to 17 years (Macek & Mitola, 2006). Their findings were consistent with that of another study which also used secondary data analyses on 10,180 children and adolescents aged 2 to 18 years and which showed that no difference in caries experience existed among children in different weight-status categories (Kopycka-Kedzierawski et al., 2008).

Furthermore, a primary research study carried out by Sadeghi and Alizadeh (2007), which included 6 to 11 year old children, showed that BMI did not relate to DFT/dft indices. Similarly, a study in Netherlands conducted among five to eight year old who were attending a dental clinic (de Jong-Lenters et al., 2015) showed that the mean dmft or dmfs scores of overweight children did not differ significantly from those of healthy-weight. An important observation is that the studies with bigger sample sizes and hence more generalisable results, were conducted using secondary data and these tended to find no association.

2.3.4 Findings from previous systematic reviews on the association between weight status and caries

Among the five systematic reviews looking at the relationship between weight status and dental caries, three found no evidence of an association between the two variables (Kantovitz et al., 2006; Li et al., 2015a; Silva et al., 2013), while the other two found

that caries was associated with increased BMI (Hayden et al., 2013; Hooley et al., 2012); the latter found that low BMI was also associated with increased risk of dental caries (Hooley et al., 2012).

Further description of the findings of primary studies and systematic reviews in the area based on their methodological quality will be presented later in the thesis.

2.3.5 Potential mechanisms of association between weight status and caries

2.3.5.1 Potential mechanisms for obesity and caries

Dietary factors, primarily the high consumption of fermentable carbohydrates (sugar) have commonly been attributed as the main factor increasing prevalence of dental caries in overweight/obese participants. Thus, although both conditions have a multifactorial aetiology, both are known to be associated with dietary habits (Alm, 2008). Taking into consideration that overweight/obese children's diets are commonly characterised by a high intake of sugary and fatty foods and beverages (Hooley et al., 2012), this suggestion seems highly plausible. In addition, several studies have linked SSB consumption with both obesity (Ludwig, Peterson & Gortmaker, 2001) and caries (Marshall, 2013; Rugg-Gunn et al., 1984).

Apart from the behavioural connection, a study in Sweden (Modeer et al., 2010) provided a plausible biological mechanism that may link the two conditions. In this study, the amount of food intake per day did not differ between the normal weight and obese participants aged 14.3 years. The study showed though that obesity related to reduced saliva flow and caries, and that neither association was confounded by any of the variables (tooth brushing, dietary habits, SES). Although their findings regarding the flow rate of saliva add new insight in to what might connect obesity with caries, the authors emphasised that they could not rule out the possibility that obese adolescents may have had dietary habits that favoured caries development.

In parallel with the aforementioned study, a recent review of studies which examined the saliva of obese individuals, found sufficient evidence suggesting that the saliva of obese and lean individuals is different (Choromanska et al., 2015) in terms of composition of salivary bacteria and flow; this reinforces the notion that saliva may be the link connecting obesity and caries, either because of different composition or flow rate. Similarly to the study of Modeer et al. (2010), the authors (Choromanska et al., 2015) concluded that obese people have a lower flow rate of stimulated whole saliva, a factor which promotes dental caries.

2.3.5.2 Potential mechanisms for underweight and caries

There are several plausible mechanisms in the literature which explain how malnutrition or undernourishment may relate to dental caries. One theory about the relationship between caries and failure to grow concerns a direct relationship between severe untreated dental caries and eating ability (Hannaway, 1970; Sheiham, 2006).

When untreated or when severe, dental caries may cause infection and pain, which could affect a child's eating ability and food intake, which in turn could result in poor growth. This hypothesis is supported by the study of Duijister et al. (2013) which showed that treatment of severely carious teeth in 48 to 68 months old underweight Philippine children was associated with significant weight gain. Mohammadi, Wright and Kay (2009), also showed that following extraction of decay affected teeth in five and six-year-old children, their BMI significantly increased at the six-month follow up. They suggested that one possible explanation for the weight gain in the children following the treatment could be the re-establishment of children's dietary intake following the extraction of carious teeth, which caused pain and affected children's eating habits and consequently growth patterns in the first place. However, an association between extraction of carious teeth and weight gain was not evident in a

similar study that took place in Saudi Arabia (Alkarimi et al., 2012). This community-based RCT which targeted schoolchildren aged six to seven years that had untreated decay, showed that there were no significant improvements in anthropometric measures (i.e. weight, height and BMI) between children who received early treatment compared to the controls (Alkarimi et al., 2012). The study however, showed that when severe carious lesions were treated, children's appetite improved.

Poor diet may also result in protein-energy malnutrition (PEM) development of calculus and reduce the flow of saliva and as a result it may lead to increased levels of caries and slow growth (Cinar & Murtomaa, 2011). Furthermore, early malnutrition (i.e. a mild to moderate malnutrition episode taking place in early life) can increase caries risk in the deciduous teeth (Alvarez, 1995), perhaps through enamel hypoplasia or salivary gland hypofunction (Psoter, Reid & Katz, 2005). Salivary gland hypofunction, which includes decreased flow of saliva and buffering capacity and decreased salivary constituents (Psoter, Reid & Katz, 2005), has been linked to PEM in several studies (Johansson et al., 1992; McMurray et al., 1977). Thus, hypofunction of the salivary gland may increase the risk of caries and could be a possible mechanism linking caries with protein energy malnutrition (Psoter, Reid & Katz, 2005). Other studies have also shown that malnutrition in early childhood was associated with enamel hypoplasia of the primary teeth (Matee et al., 1992; Sweeney et al., 1969) and subsequently caries, perhaps through changes in the composition and surface of the enamel (Psoter, Reid & Katz, 2005).

Similarly to Mohammadi, Wright and Kay (2009), AlKarimi et al. (2014) proposed three mechanisms by which severe dental caries may indirectly affect growth, through body responses to chronic oral infection and/or inflammation. The first one (immune

responses) suggests that infection may affect immunity and erythropoiesis which could result in anemia, impairment of bone remodeling, and impact on sleep patterns and food intake. The second mechanism (endocrine responses) proposes that the reduction in slow wave sleep as a result of pain and infection could lead to impairment of growth hormone secretion. The last one relates to metabolic responses and suggests that undernutrition could be caused by infection related calorie wasting, increased caloric demands and reduced nutrient absorption.

2.3.6 Theoretical Framework

Evidence shows that there are striking differences in obesity and caries rates both between and within countries. In the UK, obesity and caries have consistently been shown to be more prevalent amongst disadvantaged children and to have a greater impact upon this population.

However, the difference in disease status between the poor and the affluent does not fully describe inequality. Referring to oral health inequalities, Watt et al. (2016) have also highlighted the presence of ‘social gradient’ whereas every step down the spectrum of socioeconomic position, individuals suffer worse disease outcomes. This is also evident in the case of obesity (Public Health England, 2017).

Taking into account the prevailing inequalities in the two conditions, the overarching theoretical framework regarding the relationship between obesity and caries is presented below.

2.3.6.1 Social Determinants Framework

The Social Determinants of Health Framework which has been released by the Commission on Social Determinants of Health of WHO (Commission on Social Determinants of Health, 2008, page 1) emphasises that the inequalities present are due to the living conditions that people are ‘born, live, work and age and the unequal

distribution of power, money and resources'. In turn, these so called "social determinants of health" influence the decisions and choices people make. WHO advocates that reduction in the inequalities present both between and within countries will be achieved only when conditions which create inequalities are targeted. The three steps recommended by WHO in order to achieve a reduction in inequalities include 'improvement of the daily living conditions; targeting the unequal distribution of power, money and resources; measuring the problem and assessing the impact of action' (Commission on Social Determinants of Health, 2008, page 2).

2.3.6.2 Common risk factors and determinants

The FDI World Dental Federation (2015) acknowledges that all of the main non-communicable diseases, which include amongst others obesity and oral diseases, share a number of common risk factors and have the same social determinants. This view is supported by WHO (2003) in their consultation report on the prevention of chronic conditions and several other authors who have provided an ecological perspective for targeting obesity (Lobstein, Baur & Uauy, 2004; Swinburn, Egger & Raza, 1999).

2.3.6.3 The Integrated Common Risk Factor Approach (ICRFA)

Building on the principles of Social Determinants of Health Framework and the common risk factor approach and emphasising that the narrow interpretation of the latter model (from a behavioural perspective only) will not reduce inequalities, Watt and Sheiham (2012) developed a new conceptual model. In addition to targeting risk behaviours that are common to many chronic conditions (i.e. diet, in the case of obesity and caries), the new model (ICRFA) highlights the importance of incorporating the traditional approach into the Social Determinants of Health framework. Thus, in addition to targeting behavioural risk factors that are common to many conditions, the ICRFA also calls for targeting the underlying causes of chronic diseases

(socioeconomic and political environment). Watt and Sheiham (2012), acknowledge that socioeconomic position (social class, gender, ethnicity, occupation, income) influences health through its impact on material and social circumstances, behavior and biological factors, psychosocial factors and health services; these constitute the so called-intermediary determinants of health in the model.

In terms of biological factors, although both obesity and caries are largely the result of unhealthy behaviours, the impact of unhealthy choices have been shown to be attenuated by a genetic susceptibility which exacerbates the response of individuals to these behaviours (Bouchard et al., 1990; Vieira, Marazita & Goldstein-McHenry, 2008). In addition, obesity and caries appear to be more prevalent in older children (Shang et al., 2008; Wang & Beydoun, 2007). In the case of common behavioural risk factors, diet and more specifically sugar consumption is known to adversely affect both conditions. A recent systematic review by WHO (Moynihan & Kelly, 2014) provided recommendations for reducing intake of free sugars as a means of reducing unhealthy body weight and caries risk. Furthermore, psychological factors and stress can affect people's motivation for physical activity and can influence eating patterns, while physical activity and sedentary lifestyle can have an impact of eating patterns and snacking (Glasgow Centre for Population Health, 2013). Both of these can influence obesity and caries.

In turn, the behaviours and choices people adopt which increase their vulnerability to obesity and caries, are largely driven by the social determinants of health which are the conditions of daily life (poverty, unemployment, education, housing, availability and access to good quality health care, cultural values related to activity and food, social capital and support media, characteristics of the built environment). These are in turn shaped by wider influences such as politics and the socioeconomic environment

(unequal distribution of power and resources, regulations related to food and physical activity, food, health, transport and education policies, social and welfare policies) (Commission on Social Determinants of Health, 2008, page 1; FDI World Dental Federation, 2015; Huang et al., 2009).

Watt et al. (2016, page 246) further support that the principles of Ottawa charter which include ‘Building healthy public policies, creating supportive environments, strengthening community action, developing personal skills, and reorienting oral health services’ can provide means for improving oral health. It also acknowledges the need for collaborative efforts that include stakeholders at the policy, research and community level.

Chapter 3. Overview of the PhD project

3.1 Rationale/Significance of the project

The high prevalence of obesity and caries among children in many industrialised countries, the adverse impact both can have on general wellbeing which can continue into adulthood, along with the implications for healthcare expenditure and the impact on society as a whole, makes it imperative to identify early solutions to these growing public health problems. Despite the fact that they potentially share common aetiologies, each condition is currently treated separately (Hooley, 2014).

Even though a relationship between weight status and dental decay has been postulated for many years now (Kantovitz et al., 2006), the effect size, and the direction of the relationship have not yet been established. That is, to date, research looking at whether obesity and caries are related is inconclusive in its findings. Understanding the nature of the association between the two conditions, as well as their determinants, at the individual and environmental level, seems to be an essential next step if effective measures against both obesity and caries are to be developed. Identification of children at risk would allow interventions to target risky behaviours and characteristics which determine the two conditions at an early stage in life, thereby reducing their short term and long term consequences. If such an approach were to become policy adopted by all stakeholders it might be possible to reduce the prevalent social inequalities in both conditions.

Furthermore, identification of common causal patterns and pathways could potentially allow the identification of appropriate preventive interventions. In turn, a multifaceted and multidisciplinary approach targeting risk behaviours and barriers to behavioural

change in relation to both conditions could enhance the efficiency and effectiveness of future programmes and improve children's overall health.

In the UK context, the government and several other agencies have long recognised the need to tackle obesity and caries and their determinants in early life (appendix 1), and several programmes have been established to monitor the two conditions at the national level. Recently, there have been calls and guidelines to address the two conditions simultaneously (British Society of Paediatric Dentistry, 2015; Public Health England, 2015b). These developments highlight the significance that both conditions are gaining in the public health agenda and post-date the dissemination of the early results of the research for this thesis.

3.2 Purpose and objectives of the PhD

This PhD study was a three-way collaborative project, involving Public Health England, Plymouth University and the Local Authority (i.e. Plymouth City Council). It was envisaged that the findings of this work would assist the University in contributing to the battle against health inequalities in Plymouth and improving Plymouth's children's overall health.

3.2.1 Purpose

The current work aimed to examine the relationship between obesity and caries in Plymouth children aged four to six years and to better comprehend the individual and broader determinants of the two conditions. These determinants include individual-health behaviours and characteristics as well as neighbourhood-level characteristics that could affect the two conditions.

3.2.1.1 Objectives

The PhD also aimed to examine differences in the distribution of the two conditions according to deprivation levels and the lived-in environment. Another objective was to identify factors that could be the target of future interventions to improve Plymouth children's health.

Overall, it was intended that the collective work would indicate the nature, direction and size of any associations between anthropometric measures and dental caries and would identify their major determinants, thereby allowing local public health interventions, based on evidence and a common risk factor approach, to be developed.

3.3 Structure of PhD

This PhD work consists of three parts:

- 1) A systematic review of the association between BMI and caries;
- 2) A spatial analysis of existing datasets on Plymouth children's weight status and dental caries;
- 3) A school survey of local child residents in which both caries and anthropometric measurements are recorded and analysed in relation to several characteristics.

3.4 Overview of PhD Thesis

The overview of the thesis, including the content of each chapter is presented below:

Chapter 4 systematically reviews the evidence on the relationship between weight status (as defined by BMI) and caries in children and adolescents up to age 18 years. An appraisal of observational studies published between 1980 and 2014 was conducted using a validated tool. A narrative and quantitative synthesis of the results is provided, together with a presentation of methodological weaknesses of studies.

Chapter 5 presents the results of an ecological study on obesity and caries of children living in Plymouth. For the analysis, existing datasets were utilised. The distribution of the two conditions and how this may be affected by geographic location are examined. Furthermore, the impact of area deprivation on each condition is explored.

Chapter 6 reports on the prevalence of obesity and caries in Plymouth school-age children by sociodemographic and other characteristics, and uses spatial analysis methods to examine their geographical distribution and association with community-level characteristics. The study presented here also examines the association between obesity and caries using a number of anthropometric indices, and different types of obesity. The impact of several environmental and individual level factors on the rates of the two conditions is also investigated.

Chapter 7 presents a discussion of the overall findings and reports on how these compare to other evidence in the literature. Plausible explanations behind the findings are provided and possible implications are discussed. This chapter also provides evidence-based recommendations at both international level and in the local context. The recommendations are addressed to various stakeholders, including researchers, health professionals, policy makers and government bodies. Furthermore, this chapter discusses the contribution the studies in this PhD have made to knowledge, presents the limitations of the PhD and draws conclusions based on the main findings.

Chapter 4. A Systematic Review of the Relationship between BMI and Caries in Young People

4.1 Introduction

Systematic reviews and meta-analyses are considered to be at the highest levels of the hierarchy of evidence (Biondi-Zoccai et al., 2011; Haidich, 2010; Pieper, Mathes & Eikermann, 2014; Tsafnat et al., 2014; Yuan & Hunt, 2009). They are increasingly being used to resolve controversies in a specific field of research, to identify gaps in existing knowledge and to draw reliable evidence which can help decision-making (Denison et al., 2013; Yuan & Hunt, 2009).

The NHS Centre for Reviews and Dissemination, University of York (2001, p.viii) has defined systematic review as: ‘a review of the evidence on a clearly formulated question that uses systematic and explicit methods to identify, select and critically appraise relevant primary research, and to extract and analyse data from the studies that are included in the review.’

Contrary to narrative reviews, which can be affected by the authors’ opinion, in systematic reviews, standardised and transparent methods are used to locate, select and assess the studies (Biondi-Zoccai et al., 2011). Furthermore, the latter can be reproduced by any other user as the methodology is transparent.

Meta-analysis, which commonly follows a systematic review, is considered a powerful method of statistically pooling data from relevant studies in order to reach a conclusion about a specific topic (Biondi-Zoccai et al., 2011; Glass, 1976; Haidich, 2010; Stroup et al., 2000). A meta-analysis can also be conducted independently from a systematic

review and it provides an objective summary of the research in question, gives an accurate estimate of the effect size and provides the opportunity to examine for heterogeneity between the studies (Haidich, 2010).

Despite their strengths, reviews of a systematic nature and meta-analyses are not without disadvantages. Their quality depends upon several factors, primarily the quality of the primary studies whose results are pooled (Biondi-Zoccai et al., 2011) and they are always potentially biased by small study effects (Yuan & Hunt, 2009). Furthermore, if they are conducted poorly, they can be misinterpreted and have a negative outcome on clinical practice (Yuan & Hunt, 2009).

4.2 Rationale

The reason for conducting a systematic review in this PhD was because earlier findings in the field were conflicting and because previous systematic reviews examining the issue all had methodological drawbacks and differences.

When this research commenced, there had been four systematic reviews which had examined the relationship between weight status and caries (Hayden et al., 2013; Hooley et al., 2012; Kantovitz et al., 2006; Silva et al., 2013). Another review was published in Spanish, but only conducted a qualitative analysis of the studies without assessing their methodological quality (Gonzalez Munoz, Adobes Martin & Gonzalez de Dios, 2013).

As well as having conflicting findings, the systematic reviews that were published all used different, non-validated and non-study design specific tools in order to appraise the quality of primary studies included in the review. They also examined evidence published in different time periods.

Thus, taking into consideration the methodological gaps in the literature and the fact that the relationship between increased weight status and caries remains inconclusive to date, it was believed that another carefully planned systematic review in the area was required.

4.3 Aim and objectives

This systematic review aimed to investigate and update the evidence of an association between BMI and caries in children and adolescents using a validated tool. The decision to use BMI as the only measure of obesity in the present systematic review was based on the fact that this is the most common method used to define obesity in children and adolescents worldwide. BMI is a simple, inexpensive and practical measure of obesity in children. In addition, although published thresholds for BMI exist, no validated references of obesity based on indicators such as waist circumference or triceps skinfold thickness currently exist. As a result, the vast majority of the studies in the field used BMI as the only indicator of obesity. The number of studies that had used alternatives measures of obesity (e.g. waist circumference) or direct measures of body composition when the systematic review commenced was very limited.

The review also aimed to investigate the direction of the relationship between obesity and caries if any were found to exist. Provided that the nature of evidence was appropriate, the study also aimed to quantify the relationship between the two variables. A secondary objective was to identify current limitations in the studies in the field and to identify potential future research directions.

4.4 Methods

The review protocol, including the inclusion and exclusion criteria, was set a priori. A search of the literature published between 1980 to June 2014, using electronic bibliographic databases and manual searching of bibliographic lists from relevant

publications, was conducted. The electronic bibliographic databases used included Medline, Pubmed, Cochrane Reviews, Cochrane trials, CINAHL, Embase and the search engine Google scholar. The ISI citation index was not used in the current review as it was not available at Plymouth University Library. Grey literature (such as PhD theses, governmental reports and conference proceedings), studies published in languages other than English and those whose full text was not accessible, were excluded from the review.

The year 1980 was chosen as a starting point in the review, as the significant increase of obesity occurred in the last three decades. In children, obesity has increased more than twofold in this time period, while in adolescents it has quadrupled (Ogden et al., 2014).

In order to identify possible articles that could be included in the review, a key word searching technique was adopted, using the operators “AND” and “OR” for the combination of the search terms. The search strategy is presented below:

4.4.1 Search history

(Overweight OR obes* OR underweight OR BMI OR "body mass index" OR "body mass" OR adiposity OR weight OR "body size" OR waist OR hip OR skinfold* OR Maln*)

AND

(caries OR "dental health" OR "primary dentition" OR "oral health" OR decay OR cavities OR dmf* OR dft OR dfs)

AND

(child* OR preschool OR pediater* or paediatric* OR minor OR pupil* OR Toddler* OR adolesc* OR teen* OR "young person" OR "young people" OR youth)

4.4.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria are included in Table 5.

Table 5. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
<ul style="list-style-type: none">• Dental caries measured by differences in the number of teeth or surfaces that were decayed, missing, filled or or presence/absence of caries.• BMI objectively measured.• The relationship between caries and BMI was examined in individuals less than 18 years old.• Studies analysing primary or secondary data.	<ul style="list-style-type: none">• Evidence of studies with participants older than 18 years of age.• No exclusions on gender or ethnicity.• Did not assess dental caries, BMI or the association between the two.• Self-reported measures of BMI.• Narrative reviews, case reports, letters and editorials.• Animal studies.• Grey literature (e.g. PhD dissertations, technical/government reports, conference proceedings).• Studies published in languages other than English.

All identified titles/abstracts were then imported electronically into the bibliographic database Endnote (version X7.2). After the duplicate articles were removed, the titles/abstracts of the papers were reviewed by two independent researchers.

The full text papers were then obtained either electronically or through the Plymouth University library. When it was not possible to obtain them from the two aforementioned sources, then the full papers were requested from the British Library through an inter-library loan. Thereafter, the full text of selected papers was reviewed and their inclusion in the review was agreed by two independent reviewers. Any disagreements during the screening of titles/abstracts and full texts were resolved

through discussion to reach consensus. Details regarding the individual studies that were included in the review were extracted using a data abstraction form that was pre-tested and piloted on four relevant papers (appendix 2). The form was developed based on the Cochrane Collaboration's form (intervention review-RCTs and non-RCTs) and the STROBE statement (von Elm et al., 2007); the latter is a checklist which consists of 22 elements that are considered important for assessing the reporting of observational studies.

4.4.3 Critical Appraisal

For the purpose of this systematic review, both primary studies and systematic reviews in the field were critically appraised using existing and validated tools.

4.4.3.1 Systematic reviews

The assessment of both primary studies and previous systematic reviews was equally important, to ensure that there is robust and reliable evidence on which to base decision making (Pieper, Mathes & Eikermann, 2014). In addition, it had been noted that none of the other systematic reviews in the field systematically appraised earlier reviews conducted in the field. Therefore, in order to explore what is already known in the area and address methodological gaps, the quality of the four systematic reviews that examined the relationship between weight status and caries was assessed using the validated AMSTAR - A Measurement Tool to Assess Systematic Reviews, as adapted by SIGN (Shea et al., 2007b; Shea et al., 2009) (appendix 3). The appraisal was conducted by two independent researchers and for any disagreements decisions were reached by consensus.

AMSTAR was initially developed to appraise systematic reviews which included RCTs, however it is also increasingly being used to assess systematic reviews of observational studies (Pieper, Mathes & Eikermann, 2014). The tool has been found to be reliable

(Shea et al., 2007a; Shea et al., 2007b; Shea et al., 2009) and consists of 11 items, that examine for a 'priori design; duplicate study selection and data extraction; comprehensive literature search; the use of publication status as an inclusion criterion; the list of included and excluded studies; the characteristics of the included studies; methods of assessment of the scientific quality of the included studies; the scientific quality of the included studies in drawing appropriate conclusions; the methods used to combine the findings of the studies; the assessment of publication bias; the inclusion of the conflict of interest' (Shea et al., 2009, p.1015).

The overall quality of the reviews was assessed by following the guide that the Scottish Intercollegiate Guidelines Network recommends (SIGN, 2012, p. 3): '**High quality** (++): Majority of criteria met. Little or no risk of bias. **Acceptable** (+): Most criteria met. Some flaws in the study with an associated risk of bias. **Low quality** (-): Either most criteria not met, or significant flaws relating to key aspects of study design. **Reject** (0): Poor quality study with significant flaws. Wrong study type. Not relevant to guideline'.

4.4.3.1.1 Why the choice of the particular tool?

A recent application of the tool indicated that AMSTAR had good measurement properties that were comparable to previous results in systematic reviews of RCTs; it was concluded that it was suitable for systematic reviews of observational studies, although some revisions might be helpful (Pieper, Mathes & Eikermann, 2014). In the absence of any other validated tool for the appraisal of systematic reviews of non-randomised studies, the choice of AMSTAR tool in the present systematic review, based on the evidence available, seemed to be the most prudent.

4.4.3.2 Observational studies

The evaluation of the methodological quality of the primary studies included in the current review was based on the validated checklist, “Methodological Evaluation of Observational Research Checklist” (MEVORECH) (Shamliyan et al., 2011). As recommended by the authors of the tool, the criteria and research specific flaws were set a priori.

4.4.3.2.1 Why choose this particular tool?

Although there are several validated tools for appraising the risk of bias in RCTs, the number of tools available for critically appraising observational studies is very limited (Hayden et al., 2013). Evidence shows that the use of scales and scores when assessing study quality of individual studies is problematic; furthermore, scales have not been proved to be reliable measures of validity nor are as transparent to the users of the reviews as checklists based on domains (Herbison, Hay-Smith & Gillespie, 2006; Higgins & Green, 2011; Juni et al., 1999; Sanderson, Tatt & Higgins, 2007). Thus, it was decided that a checklist based on individual elements/domains would be the most appropriate method to use in the current review.

Another reason MEVORECH was used for the appraisal of the primary studies was that it assesses not only internal and external validity, but also the applicability and the reporting quality of the studies (Shamliyan et al., 2013). Moreover, it distinguishes between validity and reporting quality without assuming that because something is not reported, it has not been conducted. In addition, MEVORECH was developed for the transparent assessment of primary studies in systematic reviews and it has previously been employed by other systematic reviews (Ijaz et al., 2013; Shaghaghi & Matlabi, 2012; Shamliyan et al., 2013; Shamliyan et al., 2011).

4.4.3.2.2 Assessment of risk of flaws

A similar approach to that followed by Ijaz et al. (2013) was employed for the critical appraisal of each study. The risk of flaw in each study was evaluated against 14 domains (elements), 10 of which were considered major and four minor. Although the evaluation of study quality was based primarily on the risk of flaw in the main domains, the evidence from minor domains and how that could affect the overall quality of the study was also taken into consideration.

The risk of flaws in each domain was categorised as low, high or unclear.

The major domains were:

- 1) Definition of exposure;
- 2) Assessment of exposure;
- 3) Assessment of outcome;
- 4) Reliability of exposure estimates;
- 5) Reliability of outcome estimates;
- 6) Confounder assessment;
- 7) Sampling bias;
- 8) Research specific bias;
- 9) Exclusion bias;
- 10) Attrition bias.

The minor domains included:

- 1) Funding;
- 2) Conflict of interest;

3) Blinding;

4) Selective reporting of results.

Below is an explanation of the main factors assessed in each domain and how the risk of flaws in each domain was assessed. For the purpose of this review, **BMI** was considered as the *exposure* and **dental caries** as the *outcome*.

- **Exposure definition**

If the intensity/dose was included in the definition/assessment of exposure, then it was considered that there was a low risk of flaw in this domain. When intensity/dose was not assessed or not reported, then the domain was given a high risk and unclear risk of flaw, respectively.

- **Source of exposure data**

When the information was obtained from medical or administrative records (data collected for health care purposes), then the source of exposure was considered as having high risk of flaw. Low risk of flaw was given if the exposure was measured by researchers specifically for the study or obtained from registries (where data were collected for epidemiologic evaluation). All studies included in the present review had to assess BMI objectively and therefore, whether exposure was subjectively or objectively measured was not used as a criterion in this domain.

- **Assessment of outcome**

This domain focused on two aspects, including the source used to measure the outcome and the validity of the outcome measure; the latter included whether radiographic examinations were used for the assessment of dental caries in addition to visual examination. If both factors were found to be of low risk, then the domain was considered to have a low risk of flaw. If one factor had high or unclear risk, then the

domain was considered of high risk. If, however, the source of the outcome measure was judged as having a high risk of flaw but radiographic examinations were also used, then the domain was classified as low risk.

- **Reliability of exposure estimates**

This domain was given a high risk of flaw when intra-observer/inter-observer variability was assessed subjectively (based on investigators' judgement) or was lower than pre-determined levels. Low risk of flaw was attributed when good inter/intra observer reliability (kappa value > 0.80 and > 0.90 , respectively) was achieved and the values were reported. When information was not available then it was marked as unclear. For case-control studies, reliability was considered to have a low risk of flaw when the exposure for both groups was assessed with the same method. When different methods were used, then it was given a high risk of flaw. If either of the two factors were given a high risk of flaw, then the domain was considered to have high risk of flaw. If one of the two domains was unclear, then total reliability of exposure was judged as unclear.

- **Reliability of outcome estimates**

When intra-observer/inter-observer variability was subjectively assessed or was lower than acceptable levels, then the domain was given high risk of flaw. Low risk of flaw was attributed when good inter/intra observer reliability (kappa value > 0.80 and > 0.90 , respectively) was achieved and the values were reported. When information was not available, then the risk of flaw in this domain was considered as unclear.

- **Confounder assessment**

This domain examined whether the major confounding factors were assessed and whether valid methods were used to assess them. For the scope of the current review, diet and SES were listed as the major confounders that could affect the relationship between BMI and caries. If both of the above mentioned parameters were at low risk of

flaw, then the domain was judged as having a low risk of flaw. If one factor had a high risk of flaw or both factors had an unclear risk of flaw then the domain was considered to have a high risk of flaw. If major confounders were assessed and the validity of the methods used was unclear, then the domain was given an unclear risk of flaw.

- **Sampling**

This domain focused on: 1) the sampling of the participants (low risk was considered when the study used a probability random sampling technique, some form of stratification or clustering, and high risk when it was a sample of convenience with or without randomisation); 2) whether sampling bias was addressed in the analysis (via weighting, post-stratification, or other methods) and 3) the response rate. An acceptable response rate in the current review was set as being above 80%.

When all factors had low risk of flaw, then the domain was considered having a low risk of flaw. If one of the factors was given a high risk of flaw or two factors had an unclear risk, then the domain was considered as having high risk of flaw. When one factor had an unclear risk of flaw, then the domain was considered as having an unclear risk of flaw.

- **Research specific flaws**

This domain included three aspects: 1) the methods used to reduce research specific bias (e.g: standardisation); 2) whether the authors assessed dose-response in the analysis and 3) whether the authors justified the sample size used.

The domain was given a low risk of flaw if all factors were considered to be at low risk. If one factor (particularly 1) had a high risk of flaw or that was unclear, then the domain was considered as being at high risk. High risk was given when two factors had high risk of flaw.

- **Funding**

The assessment of flaw in this domain focused on two elements, namely the source of funding and the role of sponsors in the analysis of data and interpretation of the findings. A study was considered to have a low risk of flaw in this domain when the funding was a grant and when the sponsoring organisation did not participate in data analyses and interpretation or when there was no funding. If any of the two parts was at high risk of flaw (i.e. study was funded through industry or through a combined industry-grant source), the study was considered to have a high risk of flaw in the particular domain. A study was considered as having an unclear risk of flaw in the particular domain, if information on any of these aspects was not provided.

- **Conflict of interest**

When there was no conflict of interest for any of the authors, the domain was considered as having a low risk of flaw. When a conflict of interest was reported for any of the authors, the risk of flaw was rated as high, and when the disclosure was not reported, the risk of flaw was marked as unclear.

- **Blinding**

This domain focused on the masking of exposure for the researchers who assessed the outcome. When the investigators were reported to not have prior knowledge of children's exposure status, then this domain was judged as being at low risk of flaw. A high risk of flaw was given if the assessors were aware of the child's exposure status, and unclear if the blinding status was not reported.

- **Exclusion**

A total exclusion rate from the analysis of greater than 25% was given a high risk of flaw and a rate of less than 25% was given a low risk of flaw.

- **Attrition**

This domain was applicable to longitudinal and case-control studies. When there was a total loss to follow up, greater than or equal to 20% (cohort studies) or when drop out among the groups differed by more than 10% or when the reasons that participants withdrew were not the same for the two groups, then the domain was given a high risk of flaw. When the total loss to follow up was less than 20% and differed between the two groups (by no more than 10% difference), then the domain was given a low risk of flaw. When the information was not available, then the domain was given an unclear risk of flaw. For case-control studies, attrition was considered to be at high risk when the percentage of non-response was different between the two groups, or when the percentage of non-response was reported only for the exposed group, or the reasons for not responding were not reported or were different between the two groups. When the percentage of non-response was documented for both groups and was the same in terms of size or cause, then the domain was given at low risk of flaw.

- **Selective reporting of results**

When all hypotheses were tested and adjusted for sources of bias, this domain was given a low risk of flaw. A high risk of flaw was given when there was incomplete/selective reporting of the tested hypothesis and/or crude estimates only were presented.

4.4.4 Synthesis of evidence

As mentioned above, quality scores for methodology were avoided. Therefore, it was decided that studies would be stratified based on the number of high risk flaws in the major elements and the conclusions would be based primarily on those studies found to be of better quality (after taking into consideration all elements and how they would affect overall study quality).

4.4.5 Meta-analysis

For the purpose of meta-analysis, the data extracted included the age group of the participants, the BMI classification system used, the risk of flaws outcome, the sample size, the effect measures and the significance level. A forest plot was used to graphically present the results of the individual studies and the overall estimated effect size and confidence interval for the true effect. Studies were included if they included the mean (and SD or SE) as the measure of effect size.

The presence of publication bias, which can result when studies of negative or no effect are not published, was assessed by visually examining the funnel plot. Furthermore, the Egger's regression test for asymmetry (Egger et al., 1997), a more objective measure of the assessment of publication bias, was used to confirm the visual inspection results. The I^2 statistic (Higgins et al., 2003) was used to assess heterogeneity. A random effects model was employed to measure the size of the relationship between BMI and caries; as studies were shown to be quite diverse because of a number of sources of heterogeneity which will be discussed later (e.g. age groups, countries etc) it was believed that a random effects model would be more appropriate to assess the relationship between BMI and caries. This is because in contrast to the fixed effects model, the random effects model accounts for non-identical true effect sizes and it is recommended when heterogeneity is present (Higgins & Green, 2011). The R software environment was used for all the calculations used in the meta-analysis.

4.4.6 Reporting

The reporting of this review, took into account the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009).

4.5 Results

4.5.1 Systematic Reviews

4.5.1.1 Brief overview of the systematic reviews

Table 6 outlines the basic details with regard to the time period that the systematic reviews covered, the population targeted, the tool used to appraise the studies, and the conclusions reached.

Table 6. Main characteristics of the systematic reviews

Author, year	Period covered	Target Population	Critical Appraisal Tool	Conclusion
Hayden et al., 2013	1980-2010	Under 18 year olds	University of Wales checklist- Systematic review and meta-analysis.	“The results confirm a positive association between obesity and dental caries in the permanent dentition, although it is unclear what is the causative direction of this relationship?” (page 305).
Hooley et al., 2012	2004-2011	0-18 years	Own criteria and level of evidence.	“There is evidence that dental caries is associated with both high and low BMI” (page 24).
Kantovitz et al., 2006	1984-2004	Children, adolescents and adults	Own criteria- Definitions of evidence level based on protocol of the Swedish Council on Technology Assessment in Health Care.	“ Only three studies on children were found to provide high level of evidence (evidence level A) on the study topic and there were conflicting findings. Thus, no clear conclusion can be drawn at this stage” (page 143).
Silva et al., 2013	2005-2012- included studies published after 2010, which were not included in the systematic reviews and meta-analysis published earlier	Aged > 6 years	Downs and Black checklist - of the 27 items included in the original checklist, 18 were selected.	“The present review did not find sufficient evidence regarding the association between obesity and dental caries, and it did not clarify the possible role of diet and other possible effect modifiers on this association” (page 799).

All of the systematic reviews included children and adolescents as their target population, except that of Kantovitz et al. (2006) who also included studies that were conducted in adults. Hayden et al. (2013) and Silva et al. (2013) used existing tools for the critical appraisal of the studies, while the other two reviews (Hooley et al., 2012; Kantovitz et al., 2006) developed their own criteria. However, the tools used by the former (Hayden et al., 2013; Silva et al., 2013) were not developed specifically for the evaluation of observational studies.

4.5.1.2 Critical appraisal

The outcome of the critical appraisal of the SRs (with reply options being Y=Yes, N=No, NA=Not applicable and Can't say) is presented and described below (table 7).

Table 7. Appraisal of the systematic reviews

Question	Kantovitz <i>et al.</i> , 2006	Hooley <i>et al.</i> , 2012	Hayden <i>et al.</i> , 2013	Silva <i>et al.</i> , 2013
The study addresses a clearly defined research question.	Y	Y	Y	Can't say
At least two people should select studies and extract data.	Y	Can't say	Y	Can't say
A comprehensive literature search is carried out.	Y	Y	Y	N
The authors clearly state if or how they limited their review by publication type.	Y	Y	Y	Y
The included and excluded studies are listed.	Y	Y	N	N
The characteristics of the included studies are provided.	Y	Y	Y	Y
The scientific quality of the included studies is assessed and documented.	Y	Y	Y	Y
The scientific quality of the included studies was assessed	N	N	Can't say	Can't say

appropriately.				
Appropriate methods are used to combine the individual study findings.	N	Can't say	Y	N
The likelihood of publication bias is assessed.	N	N	Y	N
Conflicts of interest are declared.	N	N	N	N

Based on the application of AMSTAR, the reviews of Kantovitz et al. (2006), Hooley et al. (2012) and Hayden et al.(2013) scored higher than Silva's et al. (2013) review.

However, as it can be seen in Table 7 none of the previous systematic reviews in the area were without flaws. While the majority scored well when it came to descriptive questions related to the research question, literature search, studies' characteristics and how the appraisal of the studies' methodological quality was conducted, most of the reviews were limited by their ability to assess the publication bias and to declare any conflicts of interest. In some instances, it was not possible through the information provided to determine whether the review met the criteria (e.g. number of researchers selecting and extracting data, whether the quality of the studies included was appropriately appraised).

4.5.1.3 Findings of the reviews

The findings of the four systematic reviews that were conducted in the area were mixed and inconclusive. The first review (Kantovitz et al., 2006), which systematically searched and appraised studies examining the relationship between obesity and dental caries in childhood, adolescence and adulthood, concluded that the evidence from the three high-quality studies identified was conflicting and no clear conclusions could be drawn. Only one of the high-quality studies identified a positive relationship between obesity and caries. In this study, healthy-weight children were found to have less caries

in their primary and secondary dentition than their overweight peers (Willershausen et al., 2004). The authors of the review suggested that further well-designed RCTs were needed to establish the association between obesity and caries.

Hayden et al. (2013) also reported that overall, a significant relationship existed between obesity and caries in children and adolescents and concluded that the association was moderated by age and socioeconomic class. In the permanent teeth, a positive albeit small relationship between obesity and caries was identified when standardised assessments of obesity were used. However, no relationship was evident in the primary dentition.

Hooley et al. (2012) confirmed the presence of a positive relationship between the two variables and reported that a negative relationship was also present, that is low BMI was associated with higher levels of dental caries. This review, which included studies conducted in individuals less than 18 years of age, showed that the results of the five better quality studies were inconsistent and that caries related to both low and high BMI; two of the studies found that children with a higher BMI had higher caries, two did not find evidence of an association, while in another study a negative association was only found in a specific age group of children.

Due to insufficient evidence, one of the most recent reviews (Silva et al., 2013) could not draw any conclusions on the association between obesity and caries in youth aged between 6 to 20 years, nor did it establish the role of potential confounders and other effect modifiers on the association.

4.5.2 Primary studies

4.5.2.1 Search results

The processing of the search results for the primary studies is presented in Figure 1, which is based on the PRISMA flow diagram (Moher et al., 2009):

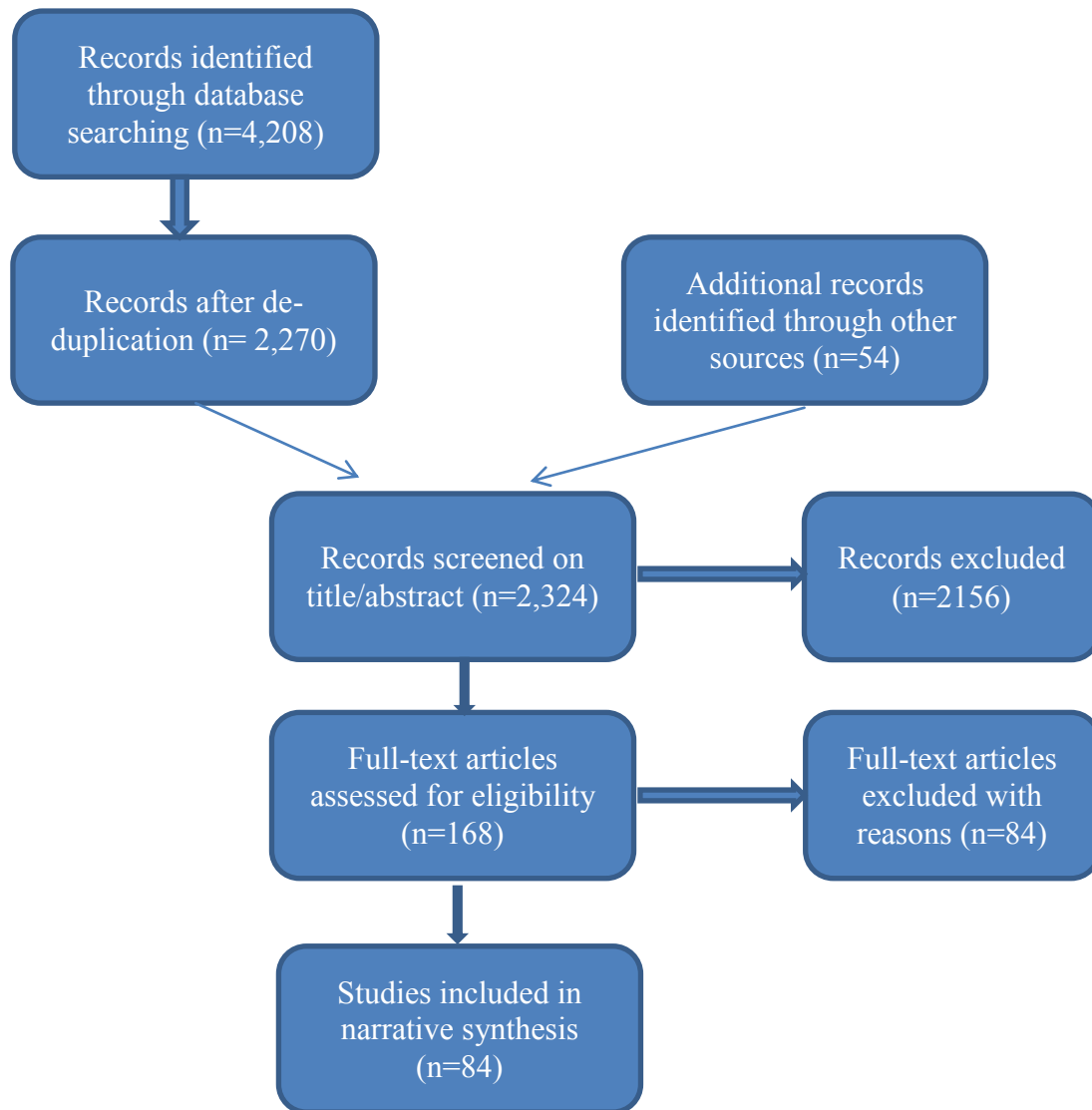


Figure 1. PRISMA Flow Diagram of search results

Initially, 4,208 potential studies were identified. Following de-duplication, 2,270 papers remained. A further 54 papers were identified from other sources. Of these 2,324 studies, 2,156 were excluded on title or abstract. Of the remaining 168 papers, 84 were excluded on full text. Full-text papers were excluded because either BMI, or the association

between BMI and dental caries, were not assessed. A list of the full-text papers that were excluded and the reason for their exclusion are provided in Appendix 4.

The inclusion criteria were met by 84 papers which were included in the systematic review.

4.5.2.1.1 Studies' characteristics

The characteristics of all studies included in the review have been summarised in a table (appendix 5) and are described below.

The countries where the studies took place were categorised into four levels of development based on the Human Development Index (HDI); this is a statistic that merges life expectancy, educational attainment and income into a single score and is commonly employed to measure and differentiate levels of 'human development' across different countries (i.e. very high, high, medium and low development) (United Nations Development Programme, no date provided). In the present review, the latest data of UNDP at the time (Human Development Report Statistical Tables 2014) were used.

4.5.2.1.2 Study design

The majority of the studies appraised were of cross-sectional design (n=74), while there were also eight case-control studies, and two studies of longitudinal design.

4.5.2.1.3 Study size

The number of participants in the included studies ranged from 55 to 10,180. The studies that had the highest sample sizes were those that used secondary data in their analysis most commonly the US NHANES. There were 18 studies with a sample population of less than 200 people.

4.5.2.1.4 Setting

Most of the studies took place in schools, whilst a small number took place in dental clinics/department, mobile offices/households and child welfare centers.

4.5.2.1.5 Geographical location

Thirty nine studies took place in very high human development (HD) countries, 28 in high HD countries, and 14 and three in medium and low HD countries, respectively, as determined by the HDI.

4.5.2.1.6 Participant characteristics

The age of the participants in the included studies ranged from 1 to 18 years. All studies except one (Cantekin et al., 2012) which only included boys, included individuals from both genders. In some studies however (dos Santos Junior et al., 2014; Granville-Garcia et al., 2008; Loyola-Rodriguez et al., 2011; Sanchez-Perez, Irigoyen & Zepeda, 2010), it was unclear from the reporting whether the sample included both males and females and some did not provide details on gender distribution (Alm et al., 2011; Costa, Daher & Queiroz, 2013; Gerdin et al., 2008; Modeer et al., 2010; Scheutz et al., 2007; Shakya, Shenoy & Rao, 2013; Tramini et al., 2009; Tripathi, Kiran & Kamala, 2010; Xavier et al., 2013).

4.5.2.1.7 Exposure (BMI)

Various BMI classification systems were used in the assessment of obesity. The majority of studies used the 2000 Centers for Disease Control and Prevention centiles (Kuczmarski et al., 2000) and the BMI for age z-scores (de Onis et al., 2007), others used the international system that the IOTF recommends (Cole et al., 2000) and few used the BMI z-scores. There were also some that used national growth references.

Notably, in some studies, there were inconsistencies in how they defined different levels of obesity.

4.5.2.1.8 Outcome (Dental Caries)

Dental caries was evaluated mainly through visual examination of teeth or tooth surfaces using WHO criteria (WHO, 1997a), although eight studies used radiographic examination in addition to the visual examination. In some studies, radiographs were taken into consideration only under certain conditions.

4.5.2.1.9 Confounder assessment

Confounders (SES and diet) were not always assessed, and even if they were, they were only partly assessed. When both confounders were assessed, most studies used a tool of unknown validity to measure them as the authors did not provide any information on the validation of the method/tool used.

4.5.2.1.10 Summary of risk of flaws

For analysing the findings, the approach suggested by the Cochrane Collaboration (Higgins & Green, 2011) was employed, which suggests presenting findings per outcome, as in Table 8.

Table 8. Findings on risk of flaws per outcome

Domains	High risk Number of studies, (%)	Low risk Number of studies, (%)	Unclear risk Number of studies, (%)	Not applicable Number of studies, (%)
Exposure definition	4 (4.8)	80 (95.2)	0	0
Assessment of exposure	10 (11.9)	73 (86.9)	1 (1.2)	0
Assessment of outcome	17 (20.2)	66 (78.6)	1 (1.2)	0
Reliability of exposure estimates	1 (1.2)	5 (6.0)	78 (92.9)	0
Reliability of outcome estimates	5 (6.0)	37 (44)	42 (50)	0
Confounder assessment	71 (84.5)	2 (2.4)	11 (13.1)	0
Sampling bias	57 (67.9)	25 (29.8)	2 (2.4)	0
Research specific bias	42 (50.0)	38 (45.2)	4 (4.8)	0
Exclusion bias	2 (2.4)	26 (31)	56 (66.7)	0
Attrition bias	2 (2.4)	4 (4.8)	3 (3.6)	75(89.3)
Funding	4 (4.8)	10 (11.9)	70 (83.3)	0
Conflict of interest	0	30 (35.7)	54 (64.3)	0
Blinding	0	8 (9.5)	76 (90.5)	0
Selective reporting of results	33 (39.3)	48 (57.1)	3 (3.6)	0

Overall, no study had a low risk of flaw in all major or minor domains. Seventy seven of the 84 studies were found to have a high risk of flaw in one or more of the major domains and 37 were found to have a high risk of flaw in at least one minor domain, most commonly the **selective reporting of results** (39%). High risk of flaw was most common in the domains of **confounder assessment** (71 out of 87 studies), **sampling bias** (56/84) and **research-specific bias** (43/84).

All but four studies were found to have low risk of flaw in the **definition of exposure** (BMI). For the **assessment of exposure**, the majority of studies were found to have low risk of flaw (73/84) while 10 had a high risk flaw. A similar pattern was observed for

the **outcome assessment**, where in 65 studies it was judged as being at low risk of flaw and in 18 others as being at high risk; in one study, the risk of flaw in this element was unclear. Only one study had a high risk of flaw in the **reliability of exposure estimates domain**, while the majority (N=78) had an unclear risk as there was not enough information provided or it was not reported at all. **Reliability of outcome estimates** was reported more frequently than the exposure estimates. Five studies were given a high risk of flaw in the reliability of outcome domain, in 37 the risk was judged as low and in 42 as unclear. Interestingly, only two studies had a low risk of flaw in the **confounder domain**, while for 11 studies the risk of flaw in the particular domain was unclear. The majority of the studies that assessed the main confounders failed to report whether they used validated tools to assess them.

For the **sampling and research specific domain**, there was a very similar distribution of high and low risk of flaw among the studies. High risk of flaw in the **exclusion bias** domain was found in two studies, 26 had a low risk of flaw while for most studies (N=56) the evidence was insufficient for conclusions to be drawn. **Attrition** was not applicable in the majority of the studies (N=74) as they had a cross-sectional design; among the cohort or case-control studies, only two had a low risk of flaw in the attrition domain. The **funding source** was not reported in the majority of the studies (N=70) and five were judged as having a high risk of flaw as they received funding/equipment from industry. None of the studies reported having a **conflict of interest**, but for 54 studies this was unclear and the remaining 30 had low risk of flaw in this element. Risk of flaw in relation to **blinding** was unclear in 76 studies, while eight were considered as having a low risk of flaw in this element. There was a similar distribution of studies with high (N=33) and low risk of flaw (N=48) in the **selective reporting of results**; only for three studies the risk of flaw in this element was unclear.

The risk of flaw in each domain across studies and for each individual study can be found in Appendix 6.

4.5.2.1.11 Summary of risk of flaws across studies

None of the studies in the present review were found to have a low risk of flaw in all major and minor domains. Seventy seven out of the 84 studies were found to have a high risk of flaw in one or more major domains and only seven studies, all of which were observational, were judged as not having a high risk of flaw in any of the key domains; however, the risk of flaw in some of the key domains in these seven studies was unclear (appendix 6).

Of the better quality studies, five studies (Dye et al., 2004; Hong et al., 2008; Jürgensen & Petersen, 2009; Peng et al., 2014a; Tramini et al., 2009) did not find evidence of an association between caries and BMI and two (Honne et al., 2012; Sakeenabi, Swamy & Mohammed, 2012) found a positive association between the two variables of interest.

With regard to the studies that identified a positive relationship, Honne et al. (2012) evaluated the association between excess weight status and caries among 463 teenagers aged 13 to 15 years in South India; the study found that a significant positive relationship between BMI, DT and DMFT. They also showed that in overweight/obese individuals the risk of caries was 3.68 higher than in those who were of low-normal weight (CI: 1.79, 7.56). A strong association between overweight/obesity and caries prevalence in children was also found in the study of Sakeenabi et al. (2012), which was conducted in a cohort of 1,550 school-age children from India. In the six year old group, children who were overweight or obese had a 1.92 and 3.6 times higher caries risk than those who were of normal weight. In 13 year olds, the risk of having caries was 1.68 and 1.8 times higher for overweight and obese children, respectively, than for normal-weight children.

The better-quality studies that analysed data on a large sample of children aged up to six years showed no association between obesity and caries (Dye et al., 2004; Hong et al., 2008); in contrast to the other better-quality studies, these two used secondary data from NHANES. DMFT was not associated with BMI in the study of Tramini et al. (2009) which included 835 12-year old French school children. The lack of a relationship between BMI and caries was also evident in the other two studies conducted in Hong Kong and Laos which included participants aged 5 and 12 years, respectively (Jürgensen & Petersen, 2009; Peng et al., 2014a). Notably, in Peng et al.'s study (2014a), although no association was found between caries and general obesity when BMI was used as an index, this was not the case when the weight-height ratio was used as an indicator of general obesity.

The studies of better quality that identified a positive association between the BMI and caries took place in India, while those that found no association between the variables of interest had relatively large sample sizes, with the exception of one study (Sakeenabi, Swamy & Mohammed, 2012).

The rest of the studies (those which were found to have one or more key domains at high risk) (N=77), most commonly did not find evidence of an association between BMI and caries (N=26). However, there were some that showed a positive association (N=13) between the two variables and others that found a negative association (N=13). The latter nature of association was not evident in the studies of higher quality.

4.5.2.1.12 Patterns of association in all studies

There were three main patterns of direction in the relationship of the variables of interest. Some studies found more than one pattern of association and these were

included in both categories. Below, a summary of the overall results with regard to the direction of the relationship between caries and BMI in the included studies is given.

4.5.2.1.12.1 Positive relationship

Dental caries was associated with high BMI in 27 studies (appendix 5). Of these studies, none had all domains at low risk of flaw. Two studies had no HR risk of flaw in any of the key domains. From the remaining, eight and 17 studies were found to have one to two and more than three key domains at high risk of flaw, respectively.

4.5.2.1.12.2 Negative relationship

Fourteen studies found that dental caries was negatively associated with BMI (appendix 5). From these studies, 11 showed that the frequency or severity of caries was higher in individuals with lower BMI, while three studies showed that caries frequency and/or severity decreased as BMI increased. Overall, seven of these studies had one to two of the main domains at high risk of flaw while the remaining seven studies had three or more of the main domains at high risk of flaw.

4.5.2.1.12.3 No relationship

In 44 studies, there was no evidence that caries and BMI were associated (appendix 5). Of these studies, five had no high risk of flaw in any of the main domains. Fifteen studies were found to have between one to two domains that were at high risk of flaw, and 24 studies had three or more of the main domains at high risk of flaw.

4.5.3 Meta-analysis

Initially, it was decided that studies with participants of less than 200 would be excluded from the review. This was based on the negative association that had been observed between sample size and effect size (Farrington & Welsh, 2003). Furthermore, larger studies have greater external validity (generalisability) while the findings of the

smaller studies can be affected by variations in the sampling and therefore are not as accurate (Farrington & Ttofi, 2009). However, this was reconsidered at a later stage as it was concluded that by excluding studies with a sample of less than 200 people, publication bias could be introduced because bigger studies tend to be published no matter their results, whereas smaller studies tend not be published if they do not show significant results. To avoid the effect of publication bias, the smaller studies were therefore included in the review.

The meta-analyses presented below firstly analyse only those studies that had a population of more than 200 people, and then analyse all the studies, including those with a population of less than 200 people. Only studies that included the mean (and SD or SE) as the measure of effect size were included.

(a) Without the small studies

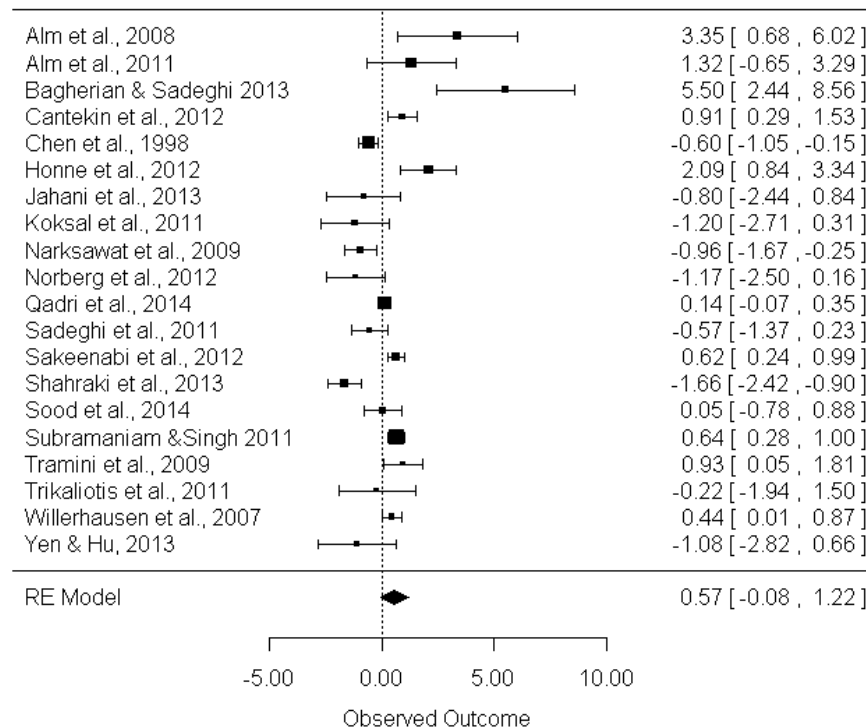


Figure 2. Forest plot displaying the relationship between BMI and caries (based on 20 studies)

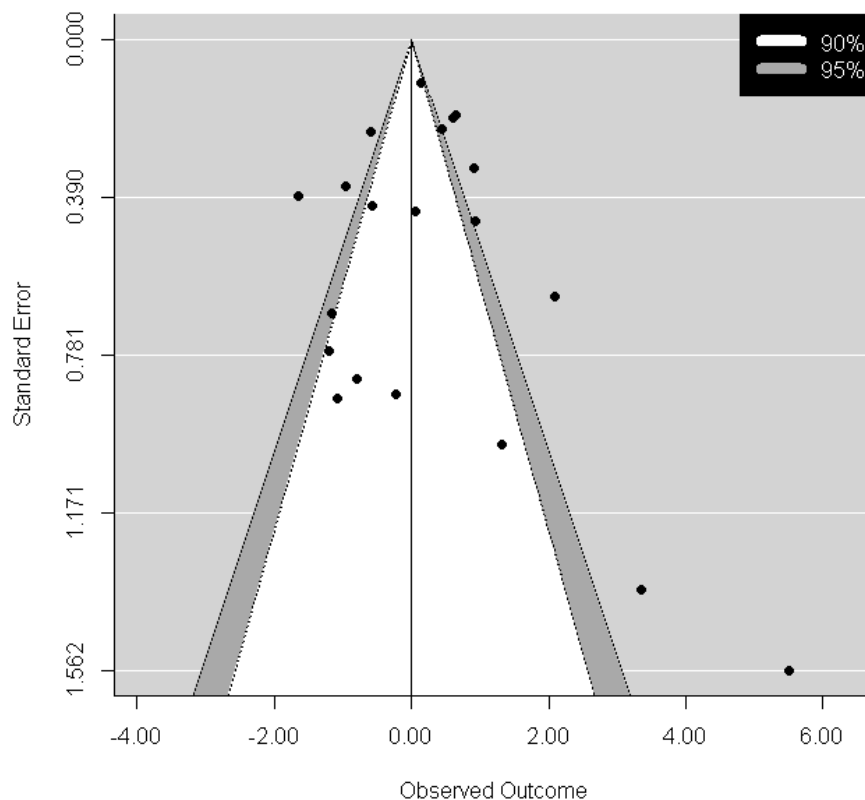


Figure 3. Funnel plot of the studies included in the meta-analysis (based on 20 studies)

When the I^2 value was examined on 20 papers (excluding those with a sample size less than 200 people), it was shown to be significant and therefore indicated the presence of heterogeneity ($I^2=91.02\%$, $Q=106.84$, $p<0.001$). The random effects model which was employed to quantify the association between BMI and caries showed no significant relationship between the two variables (effect size: 0.57; $p=0.97$; CI: -0.08, 1.22) (figure 2). Regarding the funnel plot results (figure 3), at 5% level of significance, Egger's regression test for asymmetry confirmed a lack of publication bias ($p = 0.8267$).

(b) With small studies included

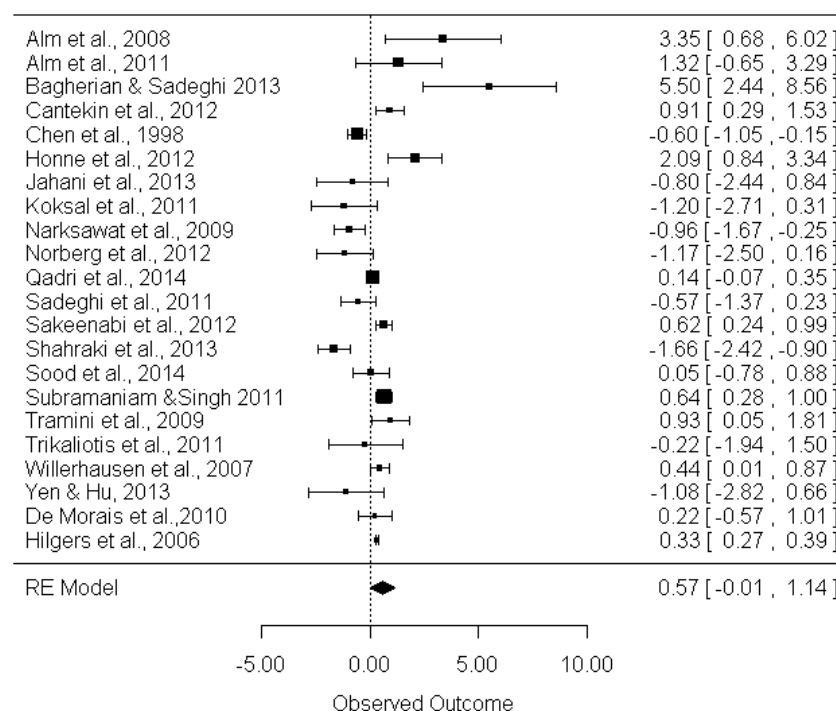


Figure 4. Forest plot displaying the relationship between BMI and caries (based on 22 studies)

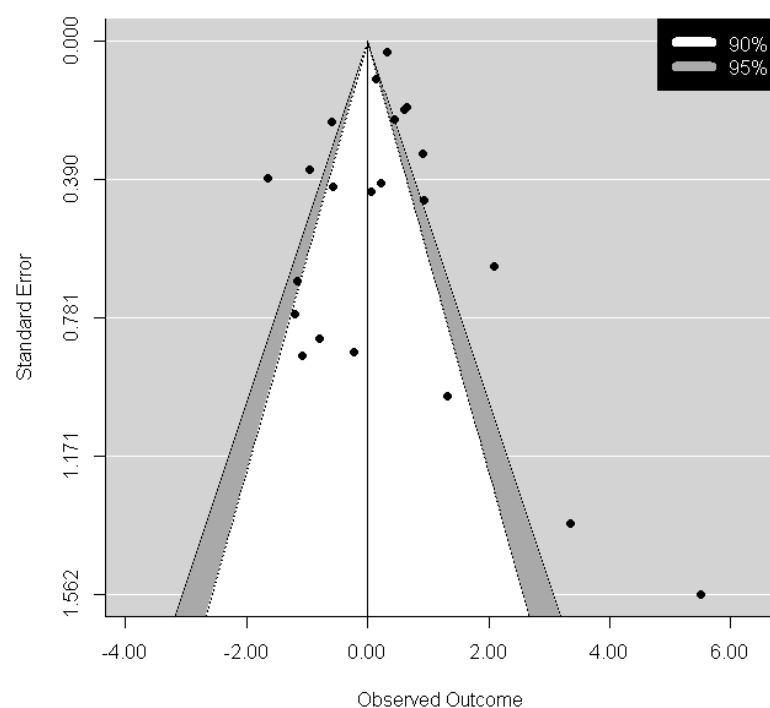


Figure 5. Funnel plot of the studies included in the meta-analysis (based on 22 studies)

Similarly, when I^2 value was examined on 22 papers (including those with a sample size less than 200 people), it was found to be significant, indicating the presence of heterogeneity ($I^2=94.21\%$, $Q=111.90$, $p<0.001$). The random effects model showed that BMI did not relate to dental caries (effect size: 0.57; $p=0.957$; CI: -0.01, 1.14) (figure 4). Regarding the funnel plot results (figure 5), the Egger's regression test for asymmetry at 5% level of significance, confirmed the lack of publication bias ($p = 0.8409$).

Thus, overall, the results of the two meta-analyses show that the findings did not differ significantly when the studies with a population of less than 200 people were included.

Due to the heterogeneity of the studies, it was not possible to draw a quantitative conclusion regarding the association between BMI and caries from the studies analysed. Also, as a result of the studies providing different measures of effect size, it was not possible to combine the results through a sub-group analysis. Therefore, although the statistical pooling was conducted and has been presented above, the conclusions of this systematic review are based on the narrative analysis of the studies that were found to be of better methodological quality; this approach is endorsed by the COCHRANE collaboration (Higgins & Green, 2011).

4.5.3.1 Sources of heterogeneity

A significant statistical heterogeneity was present in the present review, as indicated by the large value of I^2 ($>50\%$) (Higgins et al., 2003). Several factors may have contributed to the inconsistency in findings and these are listed below.

Many studies appeared inconsistent in both their diagnostic criteria for dental caries and classification of weight status. Thus, important sources of heterogeneity could be the

systems used to classify BMI (five different classification systems were used) and/or the age groups of the participants and therefore the type of dentition assessed (primary or secondary); as the studies included in this review focused on children and adolescents, assessments of dental caries were conducted on the primary and/or secondary dentition and thus the age group examined could have affected the results. The diagnostic criteria used for dental caries and the sensitivity of the dental examination (whether radiographs were used for the detection of caries) could also be a source of heterogeneity; different criteria and methods were used to assess dental caries and although the majority of the studies used visual examination for the examination, there were others that also used radiographic exams.

The different levels of study quality could also be a major source of heterogeneity. Other sources could be the different measures of effect size provided in the studies, including odds ratios, means, prevalence ratios and relative risk.

Another issue was that the relationship was not commonly examined on the whole spectrum of BMI, as there was not always representation of children from all BMI categories (underweight, normal, and overweight and obese). A point that was also reported in a previous systematic review (Hooley et al., 2012) is that sometimes, it was not clear whether underweight children were excluded from the analysis or were included in the normal weight category. This would have influenced any comparisons between the groups within a study and could have attenuated any relationships detected. Moreover, there were major differences in the statistical analyses employed.

In addition, studies took place in countries with different levels of development, and this could potentially affect the association observed between BMI and caries. It has been reported that in more wealthy populations, caries development may not follow the same

path than that observed in the more disadvantaged populations (Hooley et al., 2012) and this may increase the heterogeneity between the studies.

Other possible reasons for heterogeneity are differences in the sampling methodology. For example, some studies recruited participants from schools and included healthy populations, while others were conducted at clinics where children were visiting because of a dental condition. Other methodological differences in data collection may also have influenced the results; for example in one study, the students were asked to clean their teeth well before the oral examination.

4.6 Discussion

The present systematic review provides updated information on the association between weight status (as determined by BMI) and dental caries, using a validated and a study-design specific tool for the assessment of methodological quality. Although it was not possible to draw quantitative conclusions (i.e. effect size) about the association between the two variables, this review helped to determine the nature of the association and, more importantly to identify methodological problems that need to be addressed when conducting primary studies in this research field. The discussion below considers the findings of the systematic review in light of the literature and current knowledge and seeks to explain and delineate the reasons for conflicting findings and inconsistencies in the evidence.

In the current systematic review, there was no consistent evidence for an association between caries and either low or high BMI. This is in agreement with three of the systematic reviews that had previously been conducted in the field (Kantovitz et al., 2006; Li et al., 2015a; Silva et al., 2013), which found no evidence that obesity and caries are related. In contrast, Hooley et al. (2012) and Hayden et al. (2013) showed that a relationship between the two variables existed under specific conditions. Taking into

account the methodological differences between the reviews, the mixed findings are not surprising. As mentioned in the introductory part of this chapter, all of the systematic reviews conducted have used different tools (and criteria) to critically appraise the primary studies. Sanderson, Tatt and Higgins (2007), have pointed out that when the same studies are appraised using different tools, the quality assessments are likely to differ. Furthermore, the tools that were used for the critical appraisal in the previous reviews were either not developed specifically for observational studies, or were developed by the authors themselves and no information on their validity was provided. In addition, most reviews attempted to cover different time periods and different populations. The findings of the various reviews are therefore not directly comparable.

Although they are not absolutely consistent, the results of the better quality studies included in the present review suggest that BMI is not related to dental caries. Five out of the seven better quality studies showed that no association existed between BMI and caries, while two indicated a positive association between the two variables. Interestingly, the better quality studies in our review that found a positive relationship between the variables of interest were both conducted in India which is considered to be a developing country. In contrast, Hooley et al. (2012) had reported that studies which identified a positive relationship between BMI and caries took place mostly in the US and Europe. Our observation, that studies finding a positive association were conducted in a developing country could be due to globalisation and an increase in affluence taking place. This in turn has increased obesity rates as well as energy and fat intake (Costa-Font, Mas & Navarro-Palau, 2013) in developing countries, so that diets have become similar to those in developed and European countries. In addition, caries levels in developing countries, which have been low until relatively recently, have started to increase, most probably due to the increased consumption of sugar (Petersen et al., 2005). Another point of consideration is that our review included studies conducted up

until 2014, while that of Hooley et al. (2012) included studies taking place up until 2010. Therefore, it may be the case that changes in lifestyles and prevalence of the two conditions in the very recent past have modified the pattern of any associations and the rapidly changing world economy may be relevant to the differences between our findings and those of Hooley et al. (2012).

The complexities of measuring social gradient and socioeconomic status and relating these to the prevalence of disease were evident in two extensive systematic reviews which examined the link between obesity and socioeconomic status (McLaren, 2007; Sobal & Stunkard, 1989). These reviews revealed that there was a gradual reversal of the impact of socioeconomic status on weight status between developed and developing countries. The first review indicated that for women, men and children in developing countries, there was a significant direct relationship between socioeconomic status and excess weight, with people in higher socioeconomic strata being more likely to be obese. In industrialised societies though, an inverse association was observed in women, but the picture in men and children was less clear. Similarly, McLaren (2007) showed that the proportion of positive associations between obesity and deprivation decreased for both men and women as one moved from high-to medium-to low HDI countries. Although both reviews focused only on obesity and socioeconomic status, they strengthen the argument that demographic and socioeconomic transitions could be responsible for the development of chronic lifestyle-related conditions. This could go some way to explaining the positive relationship between high BMI and caries that this review identified in developing countries.

With regard to the mechanisms driving these patterns, it could be that people from developed countries in higher socioeconomic groups have a healthier diet, which reflects the person's economic capacity to purchase these foods, as they tend to be more

expensive (McLaren, 2007). In contrast, lower-income individuals are more likely to consume low-quality foods which tend to be cheaper and higher in sugar and fat content (Darmon & Drewnowski, 2008), and this can negatively affect weight and oral health status. Also, where food availability is low, the ability to buy food is a significant parameter in the socioeconomic pattern of weight. In their systematic review, Hooley et al. (2012) stressed that the development of caries in disadvantaged groups may follow a different path from the more affluent groups. Overall, these observations highlight the complexity of the relationship between economic growth and obesity and highlight why the systematic review was unlikely to reveal a simple association between caries and obesity. As there has been a shift towards people in lower socioeconomic groups in developing countries being more obese (Monteiro et al., 2004), future studies need to examine how SES in both developed and developing countries affect the relationship between the two conditions.

The inconsistency of the findings regarding the relationship between obesity and caries in the present review could also in part be due to the fact that BMI was the only measure of obesity examined. BMI may not be the best index of obesity when assessing the relationship between the two variables (as it cannot differentiate between fat, muscle or bone mass) while peripheral and central obesity are more important as markers of disease risk (Peng et al., 2014a). This argument gains strength from several studies who showed that obesity and caries were related when other types or indices of obesity, rather than BMI, were used (Peng et al., 2014b; Peng et al., 2014a). Thus, it could be that a particular type or index of obesity determines the pattern of the relation between obesity and caries. However, evidence of an association between different types of obesity and caries is also not consistent. For example, in children aged 12 years an association between both central and peripheral obesity and dental caries was observed

(Peng et al., 2014b), however, in five-year olds only central obesity related to caries (Peng et al., 2014a). Age therefore also seems to affect the relationship in some way.

With regard to age, our systematic review included participants only up to 18 years of age. Subgroup analysis in a quantitative form (between primary and secondary dentition) was not possible due to the heterogeneity in the studies. It is therefore likely that the inconsistent relationship between the BMI and caries is a consequence of the wide range of ages of the children included in the primary studies. The evidence in the field regarding the association is stronger and more consistent for the permanent dentition (British Society of Paediatric Dentistry, 2015; Public Health England, 2015b). The systematic review and quantitative analysis carried out by Hayden et al. (2013) concluded that there was a relationship between BMI and caries in the secondary dentition only. One explanation given was the increased sedentary lifestyle among older children and the unhealthy dietary behaviours associated with it (i.e. snack consumption of energy dense food, increased meal frequency) and these behaviours increase the risk of both obesity and caries. Other possible explanations given for the impact of age on the relationship detected, are the different growth rates of children within the same group (Hayden et al., 2013) and the changes in the formation of enamel which occurs during adolescent growth spurt (Li et al., 2015a). The mechanisms were not examined or considered in the present review.

A further consideration with regard to the inconsistent results is that the present systematic review examined obesity as measured by anthropometric methods (i.e. BMI vs laboratory methods). In a study carried out by Costacurta et al. (2011) it was found that when BMI was used as an indicator of weight status, no association between increased dental caries experience and pre-obesity/obesity was found, which echoes the finding of the present systematic review. However, in the study of Costacurta et al.

(2011), a significant positive association was found in both the primary and secondary dentition when DXA measurements were used. The authors therefore concluded that BMI measurements were not consistent with those of DXA and suggested that misclassification of children's weight status when using BMI could be a reason for the conflicting findings in the field (Costacurta et al., 2011). However, in a cross-sectional study, that was conducted among 986 18-year old adolescents, which assessed overweight and obesity by another laboratory method (air displacement plethysmography), it was shown that increased weight status did not relate to dental caries experience (Justo Fde et al., 2015), thus weakening the assumption that it is the use of BMI that introduces error. Overall, it appears that future studies may benefit from the addition of other indices and measures of obesity, as they provide complementary information (Peng et al., 2014b; Peng et al., 2014a). The application of laboratory methods such as DEXA and air displacement plethysmography may well provide more accurate insights into the relationship between obesity and caries. However, whether such studies can be justified is debatable, as their conduct would be extremely expensive.

Differences in methodology in the primary studies may also have led to the observed inconsistent results. For example, there were differences in sampling methodology, data collection, assessment of dental caries and obesity, diagnostic criteria, setting and statistical analyses which could all have altered the overall results. All of these could also have impacted on the quality of the primary studies and therefore on the quality of the review. In particular, a notable finding in the review was the absence of adjustment for confounders such as diet and SES in many of the studies. Several other effect modifiers such as ethnicity were also not always accounted for. The lack of adjustment renders the results of these studies questionable as confounders are likely to have an important effect on the observed associations when conditions with complex causal

factors such as obesity and caries are studied. Confounders can erroneously increase or decrease the magnitude of the association and even reverse the direction of the relationship (Kamangar, 2012). Therefore, the findings of the primary studies may have been affected and the true effect size may have been distorted (Hajian Tilaki, 2012). Given that the quality of the systematic review would have been affected by the quality of the original studies (Yuan & Hunt, 2009) and because bias and confounding affects meta-analysis (Zwahlen, Renahan & Egger, 2008), no definite conclusions can be drawn from the present systematic review. Although every effort was made to minimise the impact of low quality studies on our results, by drawing our conclusions only from the high-quality studies, it is important to take into account the questionable validity of some of the primary studies that were included in the review.

Another noteworthy observation in the present review were the differences in the sampling and data collection in the original studies. Although the majority of studies took place in the school setting and involved healthy participants, there were others that were conducted in paediatric clinics/departments. In these latter studies the children included were more likely to have high caries as they were only present for recruitment because of their poor oral condition. Other studies included children that were involved in oral health preventive programmes and therefore it is possible that the parents of these children were more conscious of their children's oral health behaviour. Thus, biases were clearly present in some of the studies and this could also have affected the relationships detected.

A final observation is that differences were observed in both assessment and diagnosis of dental caries. The majority of studies used visual examination of decay, which meant they may have estimated the level of caries in the population differently to radiographic studies. Differences in method of caries measurement may have distorted the effect size

of a relationship between BMI and caries in some studies (Lempert et al., 2014) and consequently the findings of the present review and other reviews. These measurement issues could therefore be another important source of heterogeneity among the primary studies. Having said this, the use of X-rays in epidemiologic studies is highly questionable due to the ethical issues raised by the unnecessary exposure of healthy individuals to radiation and also because the cost of the examination would be difficult to justify (Neuhaus et al., 2009). Similarly, differences in the BMI classification systems used in the different studies would have also introduced variation in results. Previously, it has been shown that the BMI cut-points used had a major impact on the magnitude of effect size of the association between obesity and periodontitis (Suvan et al., 2011) and as a result, it introduced heterogeneity between the studies. Thus, it is plausible that the classification systems employed in the studies of the present review may have affected the effect size identified.

Overall, although there was some evidence that BMI and caries are positively related, our systematic review suggests that this is not consistent. The review has also identified several methodological weaknesses in the primary studies in the field, which if addressed, would significantly improve the methodological rigour of research in this field and therefore the quality of any subsequent systematic reviews. This in turn would enable researchers to draw valid conclusions about the evidence of an association between obesity and caries. It is clear that a consistent approach to research about the relationship between caries and weight status is needed before explicit conclusions about it can be drawn. Our recommendations about how the research could be improved are made later in this thesis.

4.7 Challenges

During the conduct of the review, a number of difficulties relating either to the nature of the systematic review process itself or the area of research were encountered.

There was no homogeneity with regard to how studies diagnosed dental caries and classified weight status and this posed difficulties when comparing the results across studies. As mentioned above, for the assessment of weight status, several classification systems were used and different diagnostic criteria for dental caries were employed in the studies.

Another issue was that weight status categories (underweight, normal, overweight, obese) and most commonly the underweight category, were not always adequately represented; therefore, the relationship between the variables was not examined across the whole spectrum of BMI. Some authors chose to merge weight group categories which did not have adequate numbers to form a group on their own.

A further limitation was the lack of adjustment for confounding variables in several studies which means that the true effect size may have been distorted (Hajian Tilaki, 2012).

The assessment of risk of flaws was also challenging. The tool that was used has numerous criteria and therefore it was extremely time consuming. However, it enabled a comprehensive assessment of risk of flaws which is necessary for evidence-based research (Shamliyan et al., 2013).

Poor reporting was common among many studies, particularly those who were of lower methodological quality and therefore assessment of a number of the domains was difficult. Consequently, more time was required to appraise the quality of these studies compared to the time spent appraising the better-designed studies.

Although predetermined criteria and flaws were set, a lengthy discussion was needed between the reviewers in order to establish that there was the same understanding of the criteria.

The authors of the tool do not provide information as to how to grade the level of evidence, although this appears to be in their future plans (Shamliyan et al., 2013). As such, evaluating the level of evidence and synthesising the results was particularly challenging.

4.8 Limitations

The current review was limited by its ability to quantify the relationship between BMI and caries or examine the existence and direction of a relationship between the two variables. This was due to the heterogeneity present in the studies in the field. Despite this, the decision not to conduct a meta-analysis was based on the danger of drawing false conclusions by combining the findings of heterogeneous studies as it would be like comparing ‘apples and oranges’ (Higgins & Green, 2011).

Another limitation of the current review is that only published studies were included, and more specifically those that were published in English language which were fully accessible. As such, the review may have been prone to selection, publication and validity bias and the results may have been affected by this (Gregoire, Derderian & Le Lorier, 1995). Reports suggest that small studies, whose results are not significant, tend not to get published, in contrast to studies whose findings are significant and are commonly published in English journals with a high impact factor (Farrington & Ttofi, 2009).

Also, the significant methodological drawbacks in the studies conducted in the field clearly influenced the results of our systematic review, as a review’s quality is

dependent on that of the primary studies. We attempted to limit this possibility by drawing conclusions only from the high-quality studies.

4.9 Conclusions

In this systematic review, no study was found to have low risk of flaw in all key elements and methodological limitations were identified in most of the studies in the field. The conclusions were drawn from those that had less risk of being flawed. These studies provided conflicting evidence. Most of the studies did not find evidence of an association between BMI and caries, while some provided support for a positive association.

Well-designed cohort/longitudinal studies using different measures of obesity need to be conducted in order to establish the link between weight status and caries. In particular, when the exposure (i.e. obesity) can be established before the condition/disease (i.e. dental caries) occurs, studies can provide stronger evidence for a causal relationship. The importance of examining the impact of confounders and several effect modifiers, such as socioeconomic status, diet, exposure to fluoride and others, should also not be overlooked; they should be thoroughly examined in future studies.

Standardisation of dental caries diagnosis and classification of weight status will enable better comparison of the results in the field and thus allow more accurate conclusions to be drawn about the relationship. Guidelines in a consensus statement would greatly assist in this. Sufficient reporting information that would enable other users to adequately draw conclusions on the quality of the primary studies is also warranted.

Chapter 5. Obesity and Caries in Plymouth Children: A Spatial Analysis

5.1 Introduction

Current research largely focuses on examining whether an association between obesity and caries exists, and how individual health determinants or individual behaviours may influence the two conditions. However, investigation into how location and geographical characteristics affect the distribution of the two conditions is almost non-existent.

As per the Social Determinants Framework, many environmental and social factors could contribute to obesity and caries through individual behaviours, as lifestyle behaviours are related to social and cultural environment, rather than the individual traits (Multiple Risk Factor Intervention Trial Research Group, 1982; WHO, 2008). This argument is supported by Sheiham and Watt (2000) who posit that an individual's behaviour is greatly affected by the social environment in which they reside and work; for this reason, they advocate that behaviour change should be within the framework of targeting the wider socioeconomic and cultural determinants of behaviours. The importance of social and environmental determinants in oral health was also emphasised by the US Surgeon General's Report which reiterated the significance of adopting a more holistic approach (US Department of Health and Human Services: National Institute of Dental and Craniofacial Research: National Institutes of Health, 2000) to health maintenance and prevention of ill-health. Others support this view (Spilieth, Christiansen & Foster Page, 2016).

Geographical Information Systems have great potential for informing decision-making at all levels and may assist the development of cost-effective actions, as well as

facilitating the monitoring and analysis of trends over time for various health conditions (Boulos, 2004). It has further been suggested that the application of these systems can help identify high-risk areas for various health conditions in need of intervention. Such applications can also help relate individuals' health outcomes to elements within the broader environment (Penney et al., 2014; Sherman et al., 2014), for example, the built environment.

Despite their potential, such systems are not utilised effectively/routinely by the UK National Health Service (NHS), researchers or public policy makers. Furthermore, although several programmes exist which examine dissimilarities in the prevalence of childhood obesity and caries among different areas in the UK (such as the National Child Measurement Programme and the National Dental Epidemiology Programme for England), the application of geographical methodologies and spatial epidemiology in the study of both diseases both at local and international level is extremely limited.

Some researchers have employed geographical information systems, and more specifically spatial analysis methods. A study in Canada, that used data from a national survey, identified clusters of overweight and obesity and emphasised the importance of developing strategies that are geographically focused and take into consideration the needs of the population (Pouliou & Elliott, 2009). Furthermore, Penney et al. (2014), through a spatial analysis of community-level data of overweight and obesity, highlighted the need to better comprehend the role of place in the emergent patterns of obesity.

Therefore, it appears that examining the distribution of childhood obesity and dental caries at an appropriate geographical level is particularly important. This may help identify vulnerable geographical areas and could potentially improve the effectiveness and efficiency of public health interventions to target the two conditions. To our

knowledge, there has been no study in the UK examining the concurrent distribution of both conditions using spatial analysis methods and only one has been identified worldwide (Campos et al., 2011). This latter study however, conducted a spatial analysis of dental caries and weight status in preschool children, without identifying spatial clusters. Furthermore, they did not examine the impact of neighbourhood characteristics on the distribution of the two conditions.

5.2 Purpose

Therefore, the aim of the study reported in this chapter was to investigate the spatial distribution of and identify clusters of, obesity and dental caries (and as such, high risk geographical areas in need of intervention) in four to six year old children in Plymouth, UK.

Other objectives included:

- ❖ To examine the impact of deprivation on childhood obesity and caries.
- ❖ To assess the effect of deprivation on the identified patterns of distribution of the two conditions.
- ❖ To investigate whether there are differences in the prevalence of the two conditions based on the Mosaic Public Sector families belong to.
- ❖ To investigate the impact of neighbourhood characteristics on the distribution of obesity and caries.

5.2.1 Choice of population

Despite that they are both largely preventable, obesity and caries continue to affect many children and can have a significant impact both on the children and their families. Although significant improvements in dental health have been observed in the last decades, this trend has stopped or even reversed in some countries particularly in the primary dentition (Lencova, Pikhart & Broukal, 2012; Speechley & Johnston, 1996).

Therefore, it is evident that policy makers, researchers and other stakeholders need to be proactive particularly with young children. Evidence also shows that the presence of two conditions in childhood can predict both conditions later in life. Prevention of the two conditions early in life, when key habits are still being developed, offers the best opportunity to control the two conditions.

In the UK context, this age is acknowledged as a key stage in life and the rate of dental caries and unhealthy weight in five year olds on average are considered Public Health Outcome Framework Indicators in order to monitor developments in this age group (Department of Health, 2012). Furthermore, three national programmes (i.e. National Child Measurement Programme, Dental Public Health Epidemiology Programme and Children's Dental Health Survey) include this age group, indicating the significance of this life-stage.

5.3 Methodology

5.3.1 Study design and data sources

This was an ecological study of cross-sectional design, based on geographically defined populations. The spatial unit of analysis were the Lower Super Output Area (LSOA) and the Neighbourhood.

5.3.2 Methodological considerations

There were a number of reasons for choosing to use an ecological design, despite the disadvantages of such a study design:

- It was important to generate a hypothesis on a population level that could later be tested on an individual-level study. That is, the conclusions of this study would inform the design and implementation of a future study and would enable more appropriate conclusions to be drawn.

- The concurrent analysis of both datasets would enable us to examine similarities and differences in the spatial distribution of both conditions in Plymouth.
- The hypotheses tested have not been previously examined.
- The study would make it possible to investigate whether the relationships under investigation exist across specific groups and types in the population or whether they are restricted to specific geographic areas.

5.3.3 Plymouth Geography

Plymouth is a relatively deprived city with non-fluoridated water in the South West of England (Devon) and has a population of 261,546 (Office for National Statistics, 2010). The city's economy can be characterised as low waged, with low rates of productivity. In 2013, it was estimated that 11,560 (of which 10,190 were under 16) children in Plymouth lived in poverty. Poverty levels are highest in neighbourhoods with higher deprivation levels (Plymouth Fairness Commission, 2013).

The geographical terms used and their relationship to the geography of Plymouth are described below.

5.3.1 Definition of Geographical Terms

5.3.1.1 Lower Super Output Areas

Lower Super Output Areas (LSOAs) are districts that have a population of approximately 1,500 people (Public Health Plymouth: Plymouth City Council, 2012). They are not subjected to frequent boundary changes like electoral wards and are consistent in size; for this reason, they are preferable as a unit of analysis when conducting statistical analyses or when comparing trends over time (Public Health Plymouth: Plymouth City Council, 2012). Plymouth currently consists of 160 LSOAs (Public Health Plymouth: Plymouth City Council, 2012).

5.3.1.2 Neighbourhood

In the UK, the term neighbourhood is not generally used for any official or statistical purpose, but is usually considered to be a small geographical area where members have a considerable face-to-face interaction (Public Health Plymouth: Plymouth City Council, 2012). In September 2011, the Plymouth 2020 Executive Group accepted the recommendation of the Overview and Scrutiny Managements Board's Task and Finish Group, which suggested for the city to be divided in 39 neighbourhoods; the new Plymouth neighbourhoods were formally approved by the Plymouth Council in October 2011, following recommendations that were made by the 'Localities and neighbourhood working review' (Public Health Plymouth: Plymouth City Council, 2012; Public Health Team: Plymouth City Council, 2014). Plymouth therefore currently consists of 39 neighbourhoods formed through the aggregations of the city's 160 LSOAs (Public Health Plymouth: Plymouth City Council, 2012).

5.3.1.3 Localities

A locality is a population cluster which defines a group of adjacent neighbourhoods; the city's 39 neighbourhoods or 160 LSOA's are grouped together into six localities (Public Health Plymouth: Plymouth City Council, 2012; Public Health Team: Plymouth City Council, 2014). The Plymouth localities and neighbourhoods included in them are presented in Table 9.

Table 9. Plymouth localities and the neighbourhoods included within each locality (Public Health Plymouth: Plymouth City Council, 2012, p.13)

Locality	Neighbourhood
Central and North East	Beacon Park Eggbuckland Estover, Glenholt, & Derriford East Higher Compton & Mannamead Leigham & Mainstone Manadon & Widey Mutley Peverell & Hartley
North West	Barne Barton Derriford West & Crownhill Ernesettle Honicknowle Southway St. Budeaux & Kings Tamerton Tamerton Foliot Whitleigh Widewell
Plympton	Chaddlewood Colebrook, Newnham, & Ridgeway Plympton St. Maurice & Yealmpstone Woodford
Plymstock	Elburton & Dunstone Goosewell Plymstock & Radford Turnchapel, Hooe, & Oreston
South East	East End Efford Greenbank & University Lipson & Laira Mount Gould
South West	City Centre Devonport Ford Ham & Pennycross Keyham Morice Town North Prospect & Weston Mill Stoke Stonehouse

The modified Plymouth localities and neighbourhoods are presented in Figure 6.

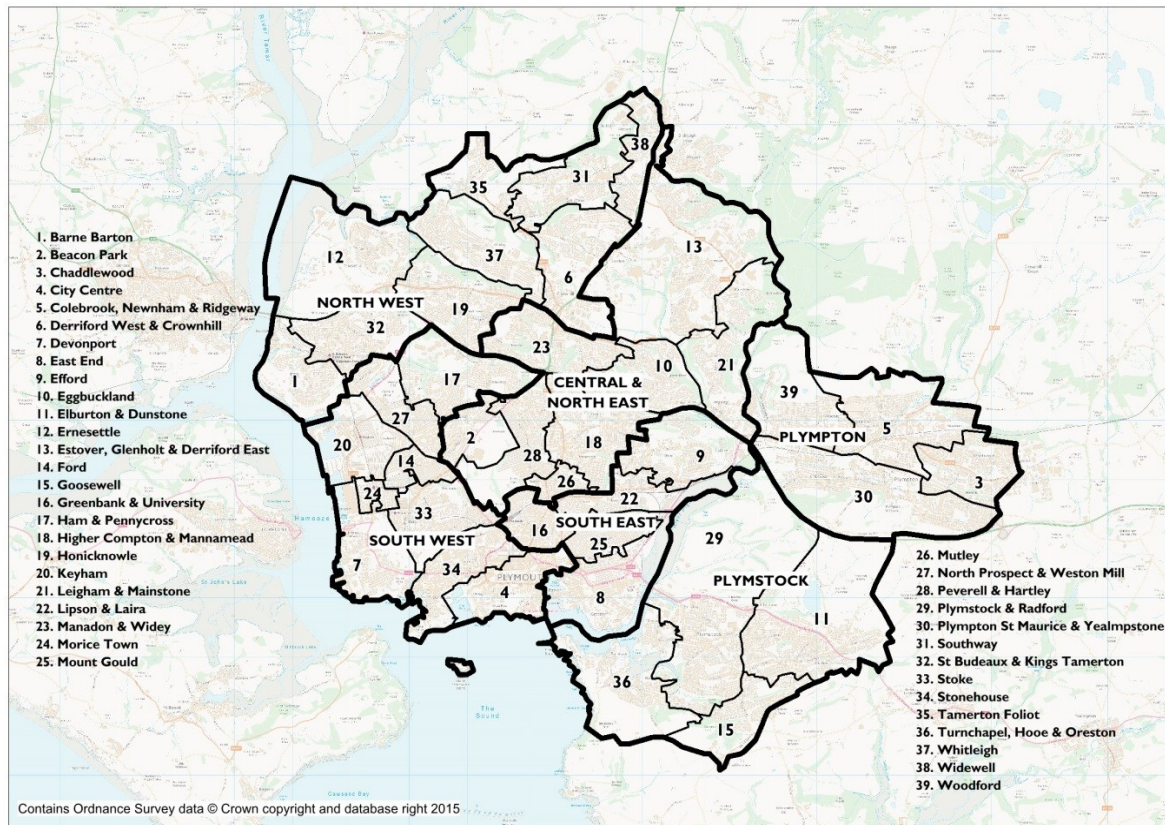


Figure 6. Plymouth by locality and neighbourhood
(Reprinted from Plymouth City Council with permission)

5.4 Methodology

5.4.1 Datasets

The data that were used in the present study were derived from two existing datasets on local children aged four to six years: (1) the 2008/9 National Child Measurement Programme (NCMP) (N=2,427) (The NHS Information Centre: Lifestyle Statistics, 2009) and (2) the 2009 Local Dental Health Survey of five year olds (N=1,425) (Witton & Nelder, 2009), which was carried out by Plymouth National Health Service (NHS) in accordance with the national protocol of the British Association for the Study of Community Dentistry (BASCD), as well as guidance published by the North West Public Health Observatory .

5.4.2 The Index of Multiple Deprivation (IMD)

Deprivation status was determined using the English Index of Multiple Deprivation (IMD) 2010. This index measures relative deprivation at LSOA level and does not consider deprivation to be an outcome of poverty only (Public Health: Office of the Director of Public Health: Plymouth City Council, 2015a). A score for every LSOA in England is calculated by grouping 38 indicators into seven domains (Department for Communities and Local Government, 2011).

Table 10 shows the domains and weights that are used to combine them.

Table 10. Domain weights for the IMD 2010 (Department for Communities and Local Government, 2011, p.16).

Domain	Weight
Income Deprivation	22.5
Employment Deprivation	22.5
Health Deprivation and Disability	13.5
Education, Skills and Training Deprivation	13.5
Barriers to Housing and Services	9.3
Crime	9.3
Living Environment Deprivation	9.3

Each LSOA in England has a deprivation score and therefore it is possible to compare different areas in terms of their deprivation (Public Health: Office of the Director of Public Health: Plymouth City Council, 2015a). However, as the IMD is not a direct measure of deprivation, it does not allow determination of how much two areas differ in terms of deprivation (Department for Communities and Local Government, 2011). Furthermore, it has been emphasised that it should not be assumed that all people who reside in deprived areas are disadvantaged, nor that all disadvantaged people reside in deprived areas (Department for Communities and Local Government, 2011).

Therefore, for each child in this study, an IMD score was assigned to their household based on the postcode. This was then grouped into one of the five IMD national quintiles (1 being the most deprived and 5 the least deprived); the latter are the outcome of IMD scores' ranking for the entire England. Therefore, it is possible to compare levels of deprivation in the sample in reference to the national population. For statistical analyses, the children's households were merged into three categories of deprivation: IMD-1 represented the most deprived and IMD-3 the least deprived.

5.4.3 Mosaic Public Sector

The UK's Mosaic Public Sector was used to complement the IMD 2010 based analysis as it estimates deprivation at the postcode level (Experian, 2006). Mosaic is a geo-demographic system which enables users to better comprehend specific areas and households in terms of their residents' lifestyle, behaviour and demographics (Experian, 2009). It is based on the principle that people with similar lifestyles and behaviours cluster together.

Taking into account 440 data elements, Mosaic classifies individuals in the UK into 69 types, 15 groups and seven Supergroups (Office of the Chief Executive, date not provided). The seven Supergroups used in the analysis allow for a high level overview of an area (Experian 2014). Tables 11 and 12 list the Mosaic Public Sector Groups and Supergroups.

Table 11. Mosaic Public Sector Groups (Office of the Chief Executive, date not provided, p.4)

Code	Groups
A	Residents of isolated rural communities
B	Residents of small and mid-sized towns with strong local roots
C	Wealthy people living in the most sought after neighbourhoods
D	Successful professionals living in suburban or semi-rural homes
E	Middle income families living in moderate suburban semis
F	Couples with young children in comfortable modern housing
G	Young, well-educated city dwellers
H	Couples and young singles in small modern starter homes
I	Lower income workers in urban terraces in often diverse areas
J	Owner occupiers in older-style housing in ex-industrial areas
K	Residents with sufficient incomes in right-to-buy social houses
L	Active elderly people living in pleasant retirement locations
M	Elderly people reliant on state support
N	Young people renting flats in high density social housing
O	Families in low-rise social housing with high levels of benefit need

Table 12. Mosaic Public Sector Supergroups (Office of the Chief Executive, date not provided, p.3).

Recode	Supergroups
A- Rural and small town inhabitants	Groups A & B
B- Affluent households	Groups C & D
C- Middle income families	Groups E & F
D- Young people starting out	Groups G & H
E- Lower income residents	Groups I, J & K
F-Elderly occupants	Groups L & M
G-Social housing tenants	Groups N & O

5.4.4 Assessment of weight status

The participants' weight status was assessed with the use of BMI and the age and gender-specific UK 1990 growth reference centiles, using the thresholds that are applied for population monitoring (Cole, Freeman & Preece, 1995). The thresholds used are shown in Table 13.

Table 13. BMI classification system (Cole, Freeman & Preece, 1995)

BMI Category	Centiles
Obese	$\geq 95^{\text{th}}$ centile
Overweight	$\geq 85^{\text{th}}$ centile
Healthy Weight	$> 2^{\text{nd}}$ - $< 85^{\text{th}}$ centile
Underweight	$\leq 2^{\text{nd}}$ centile

5.4.5 Assessment of dental caries

Dental caries was assessed using the dmft score (Pitts, Evans & Pine).

5.5 Statistical Analyses

From the statistical analyses of the NCMP, eight children who were underweight were excluded due to the small number in the sample, as were 45 other children whose postcodes placed them in areas outside Plymouth boundaries and another two for whom data was incomplete. Furthermore, 19 children who lived in areas outside the city boundary and two with incomplete data were excluded from the analysis of the Dental Survey.

Means \pm standard deviation (SD) and frequencies (%) were used to present results on continuous and categorical variables, respectively. After checking for normality, standard parametric tests were used to quantify the strength of the association between the variables of interest.

The association of deprivation (IMD 1, 2, 3) with adiposity and dental caries was determined using ANOVA and Poisson regression models, respectively. ANOVA was used to compare the children's BMI, height, and weight among the different Mosaic Supergroups, with the Bonferroni adjustment for multiple comparisons. The difference in the average dmft scores between the Mosaic Supergroups was examined using Poisson regression.

5.6 Spatial Statistics

Initially, neighbouring spatial areas (neighbourhoods) were defined based on contiguity, i.e. whether they shared a common boundary point (figure 7). If for example, an area was surrounded by five neighbourhoods, then it would be assigned a higher spatial weight compared to an area which had only one adjacent neighbourhood. Because neighbourhoods did not have the same number of neighbours, proportional weights were created through row standardisation; this involved dividing each neighbour weight for a feature by the corresponding total amount of all neighbour weights (Anselin, 1988).

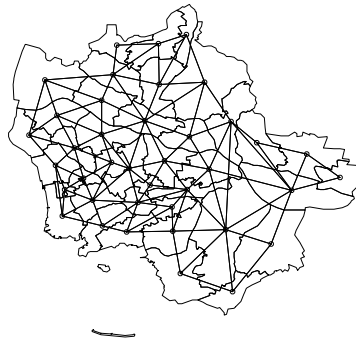


Figure 7. Assumed neighbourhood structure based on contiguity defined by neighbourhoods sharing at least one boundary point

5.6.1 Global Moran's I

A modified version of Global Moran's I, which adjusts spatial clustering according to population density, was used to quantify the overall spatial clustering at the neighbourhood level and to test whether values observed at one location correlated to values observed at neighbouring locations (Jackson et al., 2010; Pouliou & Elliott 2009). This statistic's values can indicate the nature of pattern identified (i.e. clustered, dispersed or random); it varies between -1, which indicates a high negative autocorrelation, to +1, which suggests the existence of a high positive autocorrelation; a value of 0 corresponds to no spatial autocorrelation (Pouliou & Elliott, 2009). When

similar values of neighbouring areas cluster together (i.e. high-high or low-low), then a positive spatial autocorrelation is present and when high values cluster with low values, then a negative autocorrelation exists (Pouliou & Elliott, 2009).

The Moran's I statistic is calculated using the formula below (Upton & Fingleton, 1985):

$$I = \frac{N \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{(\sum_{i=1}^n \sum_{j=1}^n w_{ij}) \sum_{i=1}^n (x_i - \bar{x})^2}$$

where

n is the number of spatial locations (here neighbourhoods)

\bar{x} is the mean of the variable (e.g. obesity/overweight rates)

x_i is the variable value at a particular location

x_j is the variable value at another location

w_{ij} is a weight indexing location of i relative to j.

5.6.2 Local Indicators of Spatial Association (LISA)

Global Moran's I cannot indicate the location of the clusters nor whether the spatial autocorrelation, if it is found to exist, is positive or negative (Pouliou & Elliott, 2009). Hence, LISA were used to locate spatial clusters and to investigate the degree to which there was a local spatial autocorrelation (Anselin, 1995). For this purpose, plots of local Moran's I value, highlighting the statistically significant outliers, were constructed ($p < 0.05$).

Empirical variograms of raw data at the LSOA level were used to examine how observations in close spatial proximity related to each other, so that the extent of spatial autocorrelation in the data could be assessed. If there is a spatial dependence, points at

close distance tend to have similar values and the spatial variogram is small (Diggle, Ribeiro Jr & Christensen, 2003).

For the current analysis, it was hypothesised that a positive linear relationship would exist between the number of children with each condition (i.e. caries and overweight/obesity) and the number of children in the sample. Indeed, the larger the number of children in an LSOA, the larger the number of children with caries and overweight/obese children. Therefore, the number of children in each LSOA in the sample was included as an *offset* in both models. The Poisson model fitted was:

$$\log(Y_i) = \alpha + \beta \times IMD_i + \log(N_i),$$

where Y_i is the number of children affected with overweight/obesity or caries in LSOA i , N_i is the number of children belonging to LSOA i in the sample, and IMD_i is the IMD score in LSOA i , where $i = 1, \dots, 160$.

5.7 Further analyses

Generalised linear models (log-linear Poisson models) were fitted to assess the significance of several covariates on caries and overweight/obesity rates at the neighbourhood level. These included:

1. Number of crimes; converted to crime rates (per unit population).
2. Number of fast food outlets; converted to density of fast food outlets (per unit population).
3. Number of grocery shops; converted to density of grocery shops (per unit population).
4. Number of dental clinics; converted to a binary variable: dental clinic(s) present in neighbourhood /dental clinics(s) not present in neighbourhood.

5. Number of people on benefits; converted to the percentage of people on benefits in each neighbourhood.

The selection of covariates was based on scrutiny of the existing scientific literature on the impact of the lived-in environment on obesity and caries and the availability of data from the Local Authority (i.e. Plymouth City Council). These variables have been shown to relate either to the prevalence of the two conditions or to potentially affect the two conditions by impacting on related health behaviours.

For example, an increase crime rate in an area may force parents to opt their children out from taking any physical activity outdoors (CDC, 2015; Davison and Lawson 2006; Glasgow Centre for Population Health, 2013). This could subsequently increase children's sedentary lifestyle (e.g. TV viewing) which has been shown to relate to increased BMI (Lazarou & Soteriades, 2010) and to promote frequent snacking and unhealthy eating habits (Lipsky & Iannotti, 2012; Olafsdottir et al., 2014) associated with obesity and caries (i.e. increased consumption of energy dense foods and drinks).

The presence of fast food outlets in an area has been shown to relate to higher obesity levels and can promote unhealthy food habits (i.e. increase consumption of energy dense foods and drinks) associated with obesity and caries (Glasgow Centre for Population Health, 2013; Jennings et al 2011; Cetateanu and Jones 2014; Lakes & Burkart, 2016).

In contrast, the presence of grocery stores has been shown to be associated with healthy BMI status (Jennings et al 2011; Cetateanu and Jones 2014) and may contribute to increased consumption of fruit and vegetables, which in turn can promote satiety and thus decrease snacking in between meals. The latter eating habit can affect both obesity and caries.

Availability and access to dental clinics may influence utilisation of preventive dental care and treatment (Curtis et al., 2007). Lastly, dependence on benefits has been shown to increase vulnerability to chronic conditions (Department of Work and Pensions, 2015) while low income may limit the healthy choices that parents can make for their children. This is because healthy foods tend to be more expensive and price can affect choices (Darmon, 2014), with lower income groups choosing to purchase energy dense foods because they are cheaper. Furthermore, low income may limit the opportunities for other healthy activities (Glasgow Centre for Population Health, 2013).

In all cases, values were corrected for different population sizes in each neighbourhood.

The IMD was not included as a covariate in the above model, as it is recorded at LSOA level and because some of the covariates considered in the log-linear Poisson models are included in the calculation of IMD.

Shape files of the boundaries of neighbourhoods were used for mapping and the spatial analysis. Results of the spatial analysis are discussed at LSOA, neighbourhood and locality levels. Data were analysed using IBM SPSS Statistics 21 and the R software. The p-values of the tests were used to determine statistical significance; small p-values (less than 0.05) suggested a significant effect/difference.

5.8 Ethical approval

All the data that were used in the current analysis, including those of the NCMP, the Local Dental Health Survey, the IMD 2010 local authority deprivation scores, the Mosaic types and sectors and shape files were provided by Plymouth Council, following the signature of an Agreement Policy. As the data were already in the public domain, no ethics approval was required in order to use them.

5.9 Results

5.9.1 National Child Measurement Program

5.9.1.1 Descriptive characteristics

The sample included 2,372 participants (N=2,372) with a mean age of 5.2 years (range 4.4 to 6.2, SD=0.02972). There were 1,147 girls (48.4%) and 1,225 boys (51.6%) in the sample. The majority of participants were of white background (N=2,238, 94.4%). Descriptive characteristics of the sample are shown in Table 14.

Table 14. Participant characteristics

Number (n)	2,372
Age (years, SD)	5.2 (SD=0.2972)
Gender (n, %)	
Girls	1,147 (48.4)
Boys	1,225 (51.6)
Ethnic background (n, %)	
White	2,238 (94.4)
Mixed	44 (1.9)
Asian or Asian British	14 (0.6)
Black or Black British	20 (0.8)
Chinese	7 (0.3)
Other	24 (1.0)
Unknown	25 (1.1)

5.9.1.2 Prevalence of overweight and obesity

As shown in Table 15, the majority of the children in the sample were in the healthy range of BMI (N=1,778, 75%). Overall, there were 246 obese children (10.4%) and 348 (14.7%) were found to be overweight.

Table 15. BMI distribution of children

BMI category	Frequency (n)	Percentage (%)
Obese	246	10.4
Overweight	348	14.7
Healthy weight	1,778	75.0
Total	2,372	100.0

5.9.1.3 National comparisons

Although the majority of the children in our sample were in the healthy range of BMI, the prevalence of children of healthy weight in 2008/09 in Plymouth (reception year) was slightly below the national average (75% compared to 76.2%) (table 16). The prevalence of both overweight and obese participants in our sample was above the national average (14.7 % and 10.4% as compared to 13.2% and 9.6%, respectively).

Table 16. National comparisons of BMI distribution for Year R children in 2008/09 (%)

	Healthy (%)	Overweight (%)	Obese (%)
Plymouth	74.9	14.7	10.4
England	76.2	13.2	9.6

5.9.1.4 Distribution of children by national quintile of deprivation

Details concerning the distribution of children according to the area of deprivation are displayed in Table 17. Thirty point one percent of the children in the sample (N=713) lived in the most deprived areas of Plymouth whereas only 7.2% (N=170) lived in the least deprived areas.

Table 17. Distribution of children by national quintile of deprivation

National Quintile	Frequency (n)	Percentage (%)
1	713	30.1
2	576	24.3
3	377	15.9
4	536	22.6
5	170	7.2
Total	2372	100.0

5.9.1.5 Mosaic Public Sector analysis

5.9.1.5.1 Mosaic Groups

Table 18 shows the distribution of the sample in the different Mosaic Groups. In our sample, a high percentage of households were classified as Group E-‘Middle income families, living in suburban or semi-rural homes’. These comprised 18% of the sample households. There was also a high number of households in Group K-‘Residents with sufficient incomes in right-to-buy social houses’ (16.1%). Group O-‘Families in low-rise social housing, with high levels of benefit need’, made up 14.4% of the sample. The next most numerous groups were Group J-‘Owner occupiers in older-style housing in ex-industrial areas’ (11.9%) and Group I-‘Lower income workers in urban terraces in often diverse areas’ (9.9%). Groups C-‘Wealthy people’ and L-‘active elderly people’ were under-represented in the sample group.

Table 18. Distribution of the sample by Mosaic groups

Code	Groups	Frequency (n)	Percentage (%)
B	Residents of small and mid-sized towns with strong local roots	82	3.5
C	Wealthy people living in the most sought after neighbourhoods	8	0.3
D	Successful professionals living in suburban or semi-rural homes	68	2.9
E	Middle income families living in moderate suburban semis	428	18.0
F	Couples with young children in comfortable modern housing	132	5.6
G	Young, well-educated city dwellers	115	4.8
H	Couples and young singles in small modern starter homes	95	4.0
I	Lower income workers in urban terraces in often diverse areas	236	9.9
J	Owner occupiers in older-style housing in ex-industrial areas	282	11.9
K	Residents with sufficient incomes in right-to-buy social houses	383	16.1
L	Active elderly people living in pleasant retirement locations	19	0.8
M	Elderly people reliant on state support	35	1.5
N	Young people renting flats in high density social housing	147	6.2
O	Families in low-rise social housing with high levels of benefit need	342	14.4
	TOTAL	2,372	100

5.9.1.5.2 Mosaic Types

Table 19 shows the top ten most common mosaic types into which children in the sample fell. The three types most highly represented included: Type O69: ‘Vulnerable young parents needing substantial state support’ (9.6%), Type E19: ‘Self-reliant older families in suburban semis in industrial towns’ (8.1%) and Type 50: ‘Older families in low value housing in traditional industrial areas’ (6.9%).

Table 19. Ranked Mosaic types

Rank	Type	Description	Frequency (n)	Sample (%)
1	O69	Vulnerable young parents needing substantial state support	227	9.6
2	E19	Self-reliant older families in suburban semis in industrial towns	192	8.1
3	K50	Older families in low value housing in traditional industrial areas	164	6.9
4	I44	Low income families occupying poor quality older terraces	140	5.9
5	J45	Low income communities reliant on low skill industrial jobs	139	5.9
6	N61	Childless tenants in social housing flats with modest social needs	137	5.8
7	K49	Low income older couples long established in former council estates	114	4.8
8	E21	Middle gaged families living in less fashionable inter war suburban semis	106	4.5
9	E18	Industrial workers living comfortably in owner occupied semis	104	4.4
10	I43	Older town centre terraces with transient, single populations	96	4

5.9.1.6 Distribution of BMI by deprivation group of residence

Table 20 displays the results of BMI distribution among the sample by deprivation group of residence. The majority of children in the sample fell within the 1st IMD category (most deprived neighbourhoods). With regard to obesity, prevalence was 3.6% higher in the most deprived group of neighbourhoods than in the least deprived (11.4% and 7.8%, respectively). Similarly, the prevalence of overweight children was 2.2% higher in the most deprived neighbourhoods (15.7%, compared to 13.5% in the least deprived). With regard to healthy-weight children, the prevalence was 5.9% lower in the most deprived group of neighbourhoods (72.9%) than in the least deprived group (78.8%).

Table 20. BMI distribution by IMD national quintile

IMD category	BMI centile categories			Total
	Obese	Overweight	Healthy	
1 (n, % within IMD category)	147 11.4	202 15.7	940 72.9	1289 100.0
2 (n, % within IMD category)	44 11.7	51 13.5	282 74.8	377 100.0
3 (n, % within IMD category)	55 7.8	95 13.5	556 78.8	706 100.0

5.9.1.7 Distribution of BMI by gender

Cross tabulation results shown in Table 21, revealed that the overall prevalence of overweight and obesity between the two genders did not differ significantly (boys 25.5%, girls 24.5%; $\chi^2 = 3.34$, $df=2$, $p=0.188$).

Table 21. BMI distribution by gender

	BMI centile categories			Total
	Obese	Overweight	Healthy	
Girls (n, % within gender category) % of total sample	106 (9.2) 4.5	175 (15.3) 7.4	866 (75.5) 36.5	48.4
Boys (n, % within gender category % of total sample)	140 (11.4) 5.9	173 (14.1) 7.3	912 (74.4) 38.4	51.6

5.9.1.8 Relationships between BMI, Weight, Height and Mosaic Supergroups

The mean BMI z-scores of children in the sample did not differ according to mosaic supergroup ($p=0.417$). Thus, there is no evidence to suggest that the Mosaic supergroups relate to overweight/obesity.

However, the average height z-score and weight z-score of children differed according to the Mosaic group children's family belonged to [$(p=0.00)$ and $(p=0.037)$, respectively]. Based on Bonferroni multiple comparisons tests (table 22) it was shown that children who were categorised as Supergroup A ('rural and small town inhabitants')⁴ had a significantly higher average height z-score as compared to those in Supergroups E or G ('lower income residents' and 'social housing tenants', respectively). Furthermore, a significantly higher weight z-score was found among children who belonged to Supergroup A than among those in Supergroup G.

⁴ In the current analysis, Supergroup A only consisted of 'residents of small and mid-sized towns with strong local roots' as there was no representation of the group 'residents of isolated rural communities'.

Table 22. Associations between height z –scores, weight z-scores and Mosaic supergroups

	Supergroups		Mean difference	Significance (p value)
Height z-score	A	E	0.4416	0.005
		G	0.5280	0.000
	E	A	-0.4416	0.005
	G	A	-0.5280	0.000
Weight z - score	A	G	0.3814	0.038
	G	A	-0.3814	0.038

Only differences which are significant are shown.

5.9.1.9 Associations between BMI, Weight, Height and IMD

No differences in the average BMI z-scores and weight z-scores of children living in different areas of deprivation were found ($p=0.070$ and $p=0.625$, respectively). Thus, local authority IMD 2010 scores did not relate to either overweight/obesity or children's weight z-scores.

However, there was evidence of a difference in the height z-score between the 3 IMD categories ($p=0.001$) (table 23). As shown in the table below, using Bonferroni multiple comparisons tests, children who lived in the most deprived areas of Plymouth had lower average height z-score than those who lived in the most affluent areas.

Table 23. Comparison of height z-scores in different IMD categories

	IMD categories		Mean difference	Significance (p value)
Height z-score	1	2	-0.1408	0.061
		3	-0.1682*	0.002
	2	1	0.1408	0.061
		3	-0.0273	1.000
	3	1	0.1682*	0.002
		2	0.0273	1.000

5.9.2 Local Dental Health Survey

5.9.2.3 Descriptive characteristics

In total, there were 1,404 participants (N=1,404) with a mean age of 5.3 years (range = 4.4 to 5.98, SD=0.3374) in the Local Dental Health Survey.

Overall, 28.8% (N=404) of the children in the sample had some experience of decay (dmft>0). With regard to dental caries experience, our findings showed that the children in the sample had on average of 0.9 teeth affected by decay (i.e. dmft=0.9, SD= 1.930).

The mean number of affected teeth in children who had some experience of decay (dmft>0) was 3.2 (dmft=3.2, SD=2.414).

5.9.2.4 Distribution of children by national quintile of deprivation

Regarding the place of residence, most of the children in the sample (N=403, 28.7%) lived in the most deprived areas of Plymouth, as defined by the national quintile IMD 2010 (national quintile-1). Only 7% of the population resided in the least deprived areas of Plymouth. Table 24 shows the detailed distribution of children in the IMD national quintiles.

Table 24. Distribution of children by IMD national quintile of deprivation

IMD National Quintile	Frequency (n)	Percentage (%)
1	403	28.7
2	330	23.5
3	238	17.0
4	333	23.7
5	100	7.1
Total	1,404	100.0

5.9.2.5 Mosaic Public Sector Analysis

5.9.2.5.1 Mosaic Groups

Table 25 shows the distribution of children in the sample into the different Mosaic groups. The Mosaic groups that were most highly represented had the same rank order as identified for the children in the NCMP. More specifically, 19.4% of the children's households in our sample were categorised as Group E-‘middle income families living in suburban or semi-rural homes’. Other highly represented groups included Group K-‘residents with sufficient incomes in right-to-buy social houses’ (16.9%), Group O-‘families in low-rise social housing with high levels of benefit need’ (13.6%), Group J-‘owner occupiers in older-style housing in ex-industrial areas’ (12.5%) and Group I-‘lower income workers in urban terraces in often diverse areas’ (8.8%). Similarly to the NCMP sample, Groups C (‘wealthy people’) and L (‘active elderly people’) were significantly under-represented in this sample.

Table 25. Distribution of the sample by Mosaic groups

Code	Groups	Frequency (n)	Percentage (%)
B	Residents of small and mid-sized towns with strong local roots	71	5.1
C	Wealthy people living in the most sought after neighbourhoods	6	0.4
D	Successful professionals living in suburban or semi-rural homes	46	3.3
E	Middle income families living in moderate suburban semis	273	19.4
F	Couples with young children in comfortable modern housing	65	4.6
G	Young, well-educated city dwellers	62	4.4
H	Couples and young singles in small modern starter homes	46	3.3
I	Lower income workers in urban terraces in often diverse	123	8.8

	areas		
J	Owner occupiers in older-style housing in ex-industrial areas	176	12.5
K	Residents with sufficient incomes in right-to-buy social houses	237	16.9
L	Active elderly people living in pleasant retirement locations	6	0.4
M	Elderly people reliant on state support	21	1.5
N	Young people renting flats in high density social housing	81	5.8
O	Families in low-rise social housing with high levels of benefit need	191	13.6
	TOTAL	1,404	100.0

5.9.2.5.2 Mosaic Types

Table 26 shows the top ten most common Mosaic types into which children in the sample fell. The three most numerous types included: Type O69: ‘vulnerable young parents needing substantial state support’ (8.8%), Type E19: ‘self-reliant older families in suburban semis in industrial towns’ (8.3%) and K50: ‘Older families in low value housing in traditional industrial areas’ (7.6%).

Table 26. Ranked mosaic types

Rank	Type	Description	Frequency (n)	Sample (%)
1	O69	Vulnerable young parents needing substantial state support	124	8.8
2	E19	Self-reliant older families in suburban semis in industrial towns	117	8.3
3	K50	Older families in low value housing in traditional industrial areas	107	7.6
4	J45	Low income communities reliant on low skill industrial jobs	82	5.8

5	N61	Childless tenants in social housing flats with modest social needs	80	5.7
6	E18	Industrial workers living comfortably in owner occupied semis	76	5.4
7	I44	Low income families occupying poor quality older terraces	71	5.1
8	E21	Middle gaged families living in less fashionable inter war suburban semis	70	5.0
9	K49	Low income older couples long established in former council estates	69	4.9
10	J46	Residents in blue collar communities revitalised by commuters	54	3.8

5.9.2.7 Distribution of dental caries by neighbourhood

There was a significant geographical variation in dmft scores at the neighbourhood level across the city, with Mutley identified as an area with high caries prevalence (figure 8).

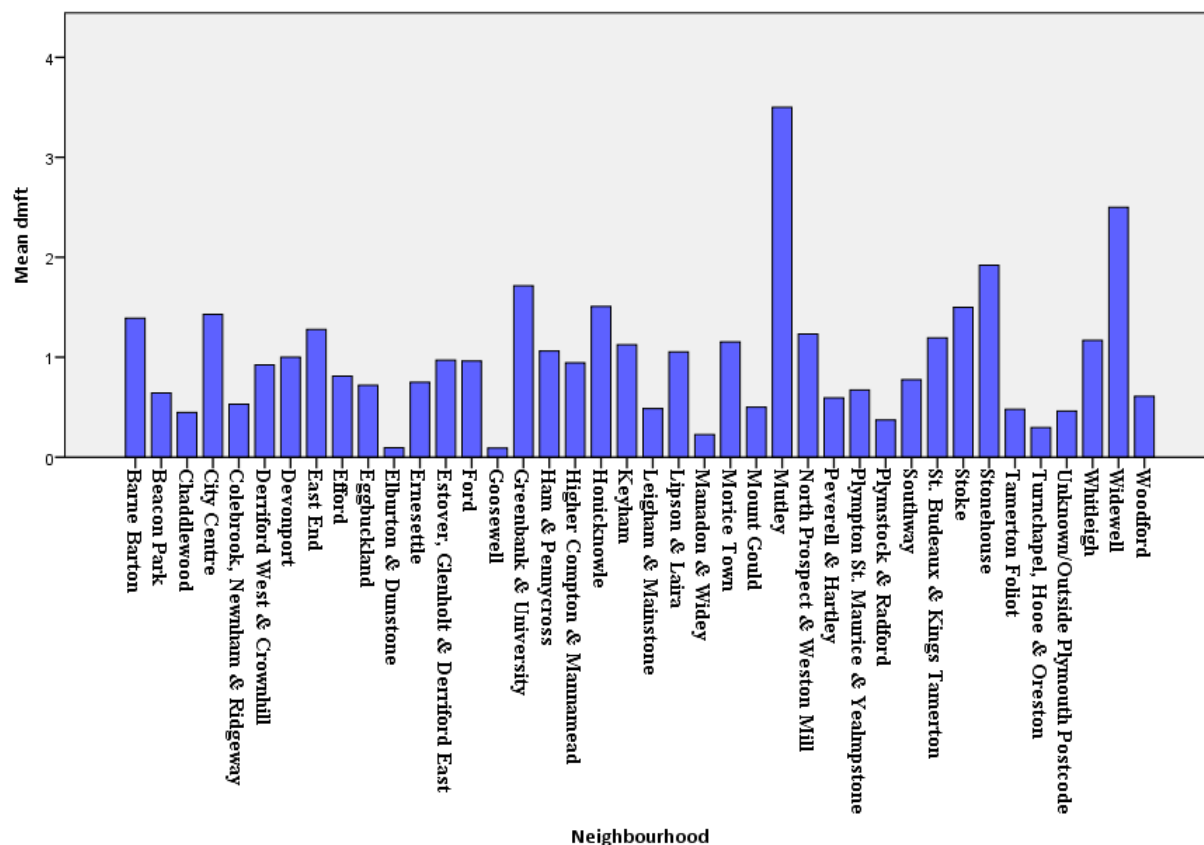


Figure 8. Average dmft of children by neighbourhood

5.9.2.8 Distribution of dental caries by deprivation group of residence

Table 27 shows the distribution of dental caries among the sample by deprivation group of residence. The majority of children with presence of decay resided in the most deprived areas of Plymouth (IMD-1, 65.7%). Only 19.6% of the children who had decay were resident in the least deprived areas (IMD-3). Among the children who were caries-free, the difference was smaller (46.3% in IMD-1 vs 35.6% in IMD-3).

Table 27. Dental caries distribution by IMD category

IMD category	Caries-free	Presence of decay	Total
1 (n, % within IMD categories, % presence of decay)	470 63.7 46.3	268 36.3 65.7	738 100 51.8
2 (n, % within IMD categories, % presence of decay)	184 75.4 18.1	60 24.6 14.7	244 100 17.1
3 (n, % within IMD categories, % presence of decay)	362 81.9 35.6	80 18.1 19.6	442 100 31

Further analyses showed that participants residing in the most deprived areas of Plymouth (IMD-1) had 1.18 teeth on average affected by decay (dmft=1.18, SD=2.095), whereas those who were living in the least deprived areas (IMD-3) had 0.5 teeth on average affected by decay (dmft=0.5, SD=1.434).

Moreover, children who had some experience of dental decay and lived in the most deprived areas, had an average of 3.24 teeth affected by decay (dmft=3.24, SD=2.316). Children with tooth decay residing in the least deprived areas had an average of 2.79 teeth affected by decay (dmft=2.79, SD=2.247).

5.9.2.9 Association between dental caries and Mosaic Supergroups

The average dmft score of the children differed according to Mosaic Supergroups. Multiple comparisons tests (table 28) showed that children who were categorised as Supergroup A-‘rural and small town inhabitants’ and Supergroup B-‘affluent households’, had a significantly lower average dmft score as compared to those who belonged to either Supergroup D-‘young people starting out’ or Supergroup G-‘social housing tenants’. Furthermore, children in Supergroup C-‘middle income families’ had also lower dmft scores when compared to those children belonging to either Supergroup D-‘young people starting out’, Supergroup E-‘lower income residents’ or Supergroup G-‘social housing tenants’. Lastly, children in Supergroup E-‘lower income residents’ were found to have lower dmft scores compared to those in Supergroup D-‘young people starting out’ and Supergroup G-‘social housing tenants’.

Table 28. Differences in dental caries between Mosaic Supergroups

	Mosaic Groups	Mean difference	Significance (p value)
Dmft score	D - A	0.9296	<0.001
	G - A	0.9323	<0.001
	D - B	0.8053	<0.001
	G - B	0.8080	<0.001
	D - C	1.1221	<0.001
	E - C	0.5974	<0.001
	G - C	1.1248	<0.001
	E - D	-0.5247	<0.001

Only differences which are significant are shown

5.9.2.10 Association between dental caries and IMD 2010

The IMD 2010 score (which was used as a continuous variable) was shown to be significantly related to dental caries ($p=0.000$). If a child’s IMD score was to increase by ten units, the logs of the expected counts would be expected to increase by 0.22 units,

and thus the expected count would increase by 1.22, while holding other variables in the model constant.

5.9.3 Spatial Analyses

With regard to the spatial distribution, results showed similar overweight and obesity rates across Plymouth. This similarity was also evident at neighbourhood level (figure 9). A Spearman rank correlation test for obesity and overweight suggested a moderate correlation between obesity and overweight rates ($\rho=0.59$, $p<0.001$). Thus, obese and overweight children were combined in one category and the rate for overweight/obesity in each neighbourhood was calculated. In what follows, the rate refers to the number of affected cases per 100 children, ‘hot spots’ refer to the clustering of high values in a particular geographical area/location and ‘cold spots’ to the clustering of low values (ESRI, no date provided).

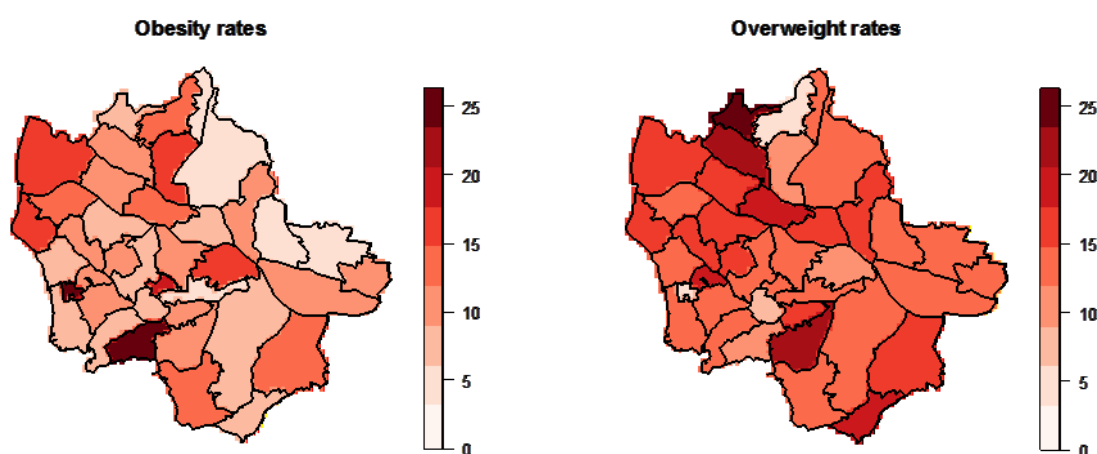


Figure 9. Obesity (left) and overweight (right) rates by neighbourhood in Plymouth

The findings revealed a significant geographical variation in the rates of childhood overweight/obesity and dental caries. The spatial distribution of the rates of obesity/overweight and dental caries rates by neighbourhood and locality are displayed in Figure 10.

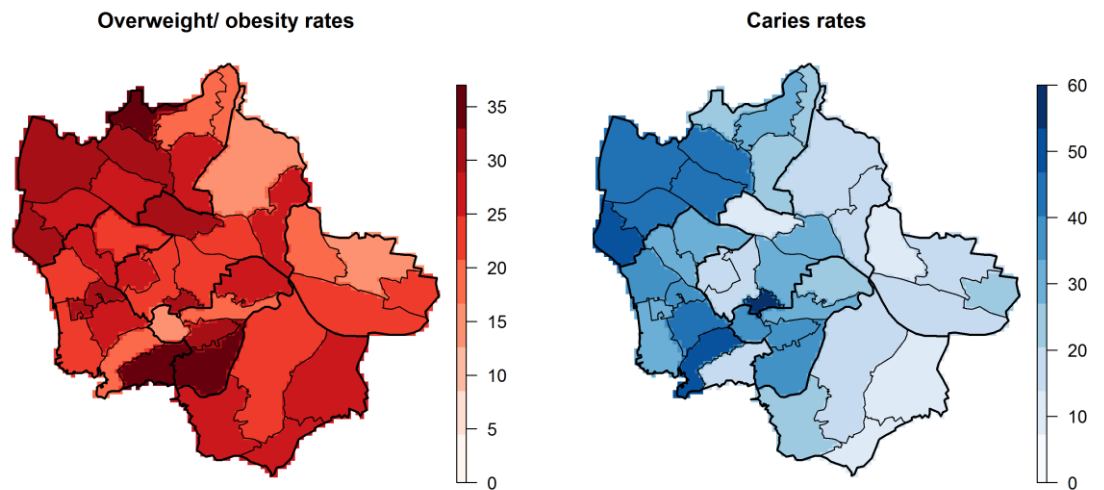


Figure 10. Overweight/obesity and caries rates by neighbourhood and locality in Plymouth

The North West, South West and South East localities had the highest rates of overweight/obesity. Notably, over one third of children in the City Centre neighbourhood were identified as being overweight or obese. Lower rates of overweight/obesity were found in the Central and North East locality.

Higher caries rates were identified in the North West, South East and South West localities; lower rates were identified in Plymstock.

Localised ‘hotspots’ of both conditions were found in neighbourhoods of South West and South East localities and more specifically in the City Centre and its adjacent East End (for obesity/overweight) and in Stonehouse and Mutley neighbourhoods (for caries). Figure 14 also suggests increasing prevalence of caries from East to West Plymouth.

5.9.3.1 Global clustering

Results for the Moran’s I test, together with the p-values are presented in Table 29.

Table 29. Spatial autocorrelation of overweight/ obesity and dental caries rates in Plymouth

	Moran's I statistic	p-values
Obesity/overweight	0.0699	0.1680
Caries	0.3339	0.0001

The results showed that there was a positive autocorrelation across neighbourhoods in caries with a value of 0.3339 ($p < 0.001$) which indicates that the overall spatial pattern of the condition was not random. The level of spatial autocorrelation was lower in obesity/overweight ($I = 0.0699$) and at a 5% level of significance the spatial autocorrelation was not statistically significant. As such, there was no strong evidence against complete spatial randomness for obesity/ overweight.

5.9.3.2 Local clustering

According to the Moran's I scatterplots (top row of figure 15), the local outliers for obesity/ overweight rates were concentrated in the neighbourhoods of Chaddlewood, Mutley, City Center and Greenbank and University, whereas for caries the outliers were located in the City centre and Mutley (by order of significance).

The LISA cluster maps for obesity/ overweight and caries rates by neighbourhood in Plymouth are shown below (bottom row of figure 11).

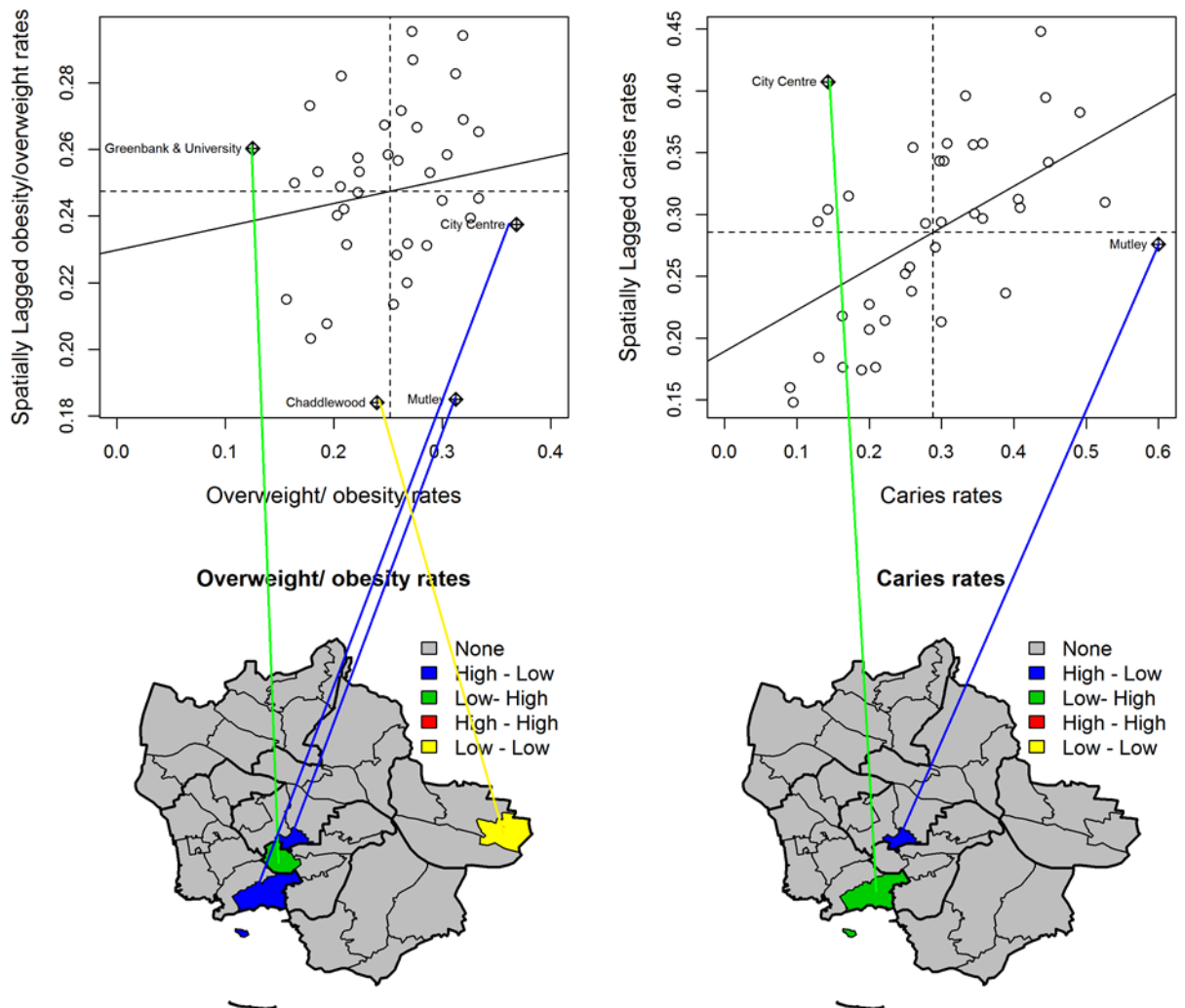


Figure 11. Local clustering of overweight/obesity and dental caries rates in Plymouth

For overweight/obesity, the Mutley and the City Centre neighbourhoods were identified as High-Low areas, whereas the Greenbank and University neighbourhood (which is located between the two aforementioned neighbourhoods) was identified as a low rate area, surrounded by high rate areas. Chaddlewood was identified as a ‘cold-spot’ neighbourhood (Low-Low area).

The results also suggest that the City Centre is a neighbourhood with a low rate of dental caries, surrounded by neighbourhoods with high rates. The Mutley

neighbourhood was highlighted as an area of high dental caries rates, with a statistically significant relationship with its adjacent neighbourhoods which were lower rates areas (High-Low area).

Thus, Mutley was identified as an area which had high rates of both caries and overweight/obesity.

5.9.3.4 Spatial autocorrelation

5.9.3.4.1 Empirical variograms

Figure 12 (a&b) shows the empirical variograms overweight/obese children and those with caries (at LSOA level). The horizontal line (the sill) is the point at which there is no spatial correlation.

For overweight/obesity counts (figure 12a) there was a pattern and a few points higher than the sill at a distance of around 2.5km, suggesting a possible negative correlation after that distance. For caries (figure 12b), there was a spatial autocorrelation up to a distance of 3km after which the variogram leveled off.

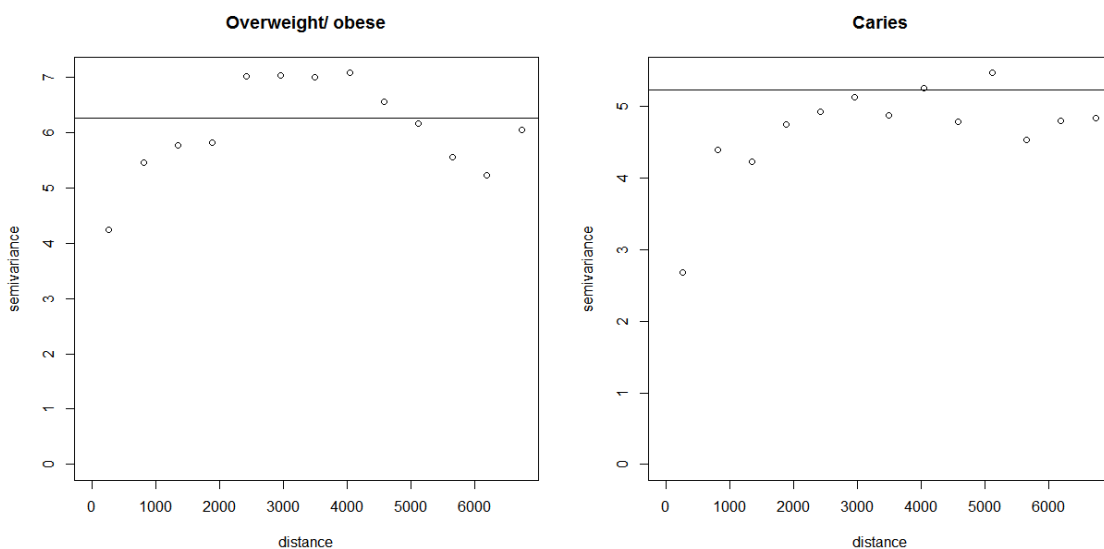


Figure 12 (a&b). Empirical variograms for raw counts of overweight/obese (left) children and children with caries (right)

5.9.3.4.2 Residual variograms

The IMD had a statistically significant impact on the rates of overweight/obese participants at LSOA level at a 5% level of significance ($p=0.0177$). The size of the effect was estimated at 0.005, suggesting that a 10 unit increase in the IMD would increase the rate of obese/overweight children by 1.05 times. If for example there were two LSOAs with a mean value of IMD 26.81 and 36.81, and the first one had an overweight/obesity rate of 0.20 (20 in 100 children were overweight or obese), then in the second LSOA the rate of overweight/obesity would be 0.21 (21 in 100 children predicted to be overweight/obese). The residual variogram levelled off at a very short distance (figure 13) and therefore no residual spatial autocorrelation appeared to exist. This indicates that IMD 2010 (deprivation) fully explained the variability in the obesity data. When a generalised additive model was also fitted, the residual spatial autocorrelation was not found to be significant ($p=0.598$).

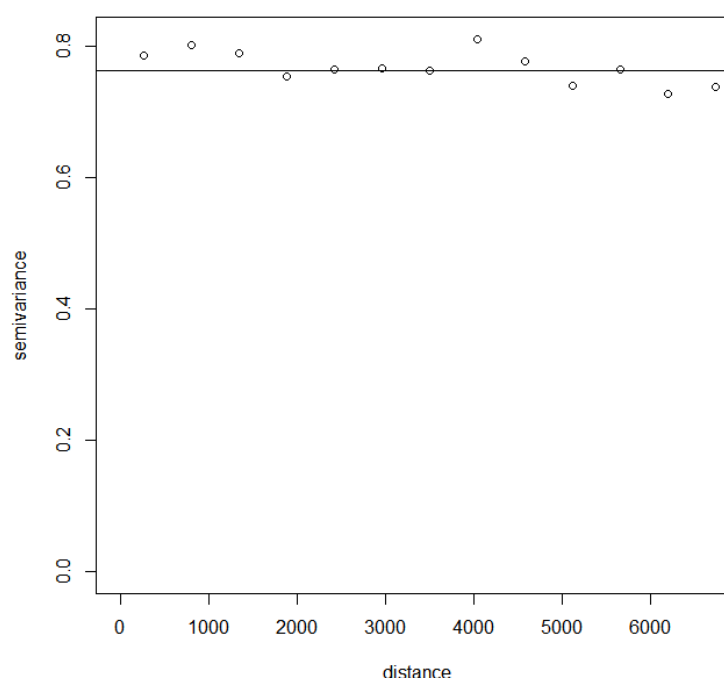


Figure 13. Variogram of deviance residuals of Poisson regression model for overweight/ obese children

The IMD also had a statistically significant impact on caries rates at LSOA level ($p < 0.001$). As the effect size was 0.019, it is estimated that an increase in the IMD of 10 units would lead to 1.204 increase in caries rates. The residual variogram levelled off at a short distance ($< 1\text{km}$ -figure 14) and therefore it appears that some residual spatial autocorrelation exists up to 1km. Thus, the IMD 2010 does not explain fully the variability in the data as residual spatial autocorrelation at small distances is present.

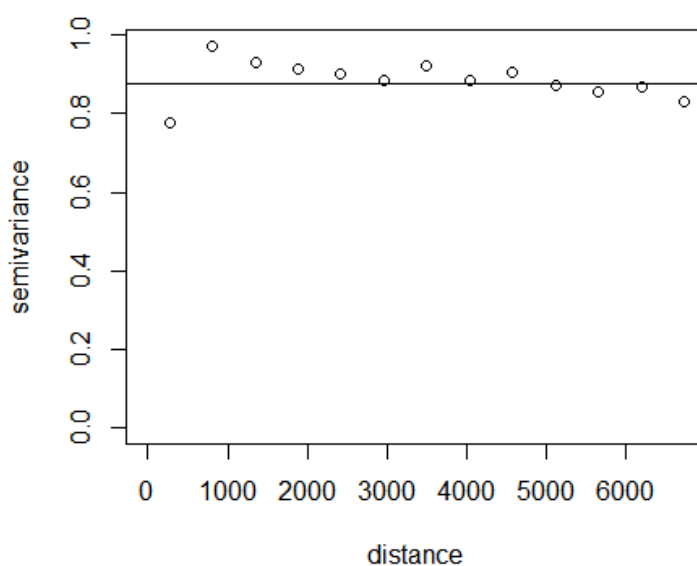


Figure 14. Variogram of deviance residuals of Poisson regression model for children with caries

When a generalised additive model was fitted, the spatial autocorrelation was found to be marginally significant ($p = 0.0495$), even after correcting for the IMD. The plot of the smooth function of the spatial coordinates of the centroids of the LSOAs is shown in Figure 15.

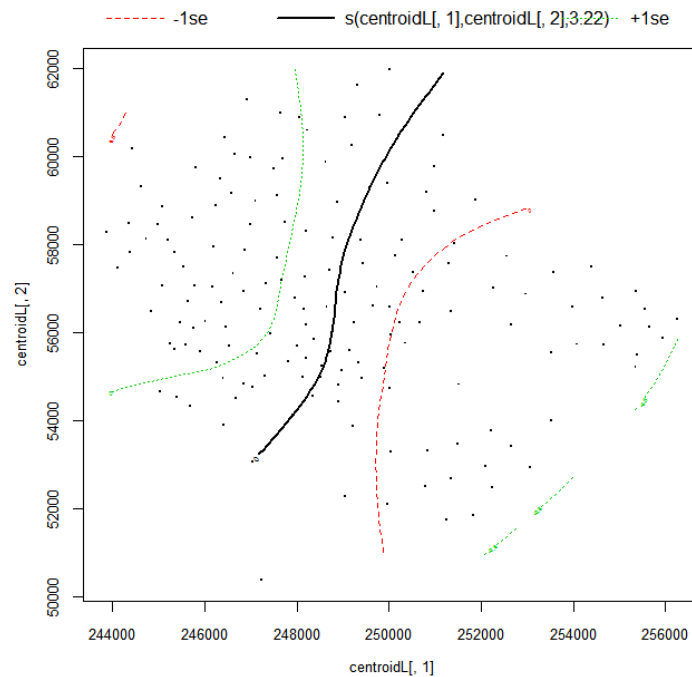


Figure 15. Smooth function of spatial coordinates for the model for the number of children with caries, where IMD is included as a covariate

This indicates a distinction between the east and west of Plymouth, with the former having higher caries values than the latter. The contours and their size suggest that the smooth function observed is subtle and not highly significant.

5.9.4 Results on environmental features/characteristics

In terms of covariates at neighbourhood level, only the percentage of people on benefits was shown to be a significant factor for caries rates ($p < 0.001$). The results indicated that a 1% increase in the percentage of people on benefits would increase the caries rates by 1.04 times. Thus, for example if two neighbourhoods had 10% and 20% of people dependent on benefits, respectively, then the number of cases of caries in the former would be expected to be 10 in 100, and in the latter to be 15 in 100.

None of the covariates examined were found to relate to overweight/obesity rates.

To further examine the characteristics of neighbourhoods identified as ‘hotspots’ or ‘cold-spots’, the average of the covariates was compared to the corresponding average

for Plymouth city (table 30). None of the variables below were significantly associated with overweight/obesity.

Table 30. Average values of covariates compared to the overall averages in Plymouth

	Percentage of people on benefits	Rate of crime	Density of fast food outlets	Density of grocery stores	Presence of dental clinic
<i>Plymouth overall averages</i>	<i>16.05</i>	<i>7.17</i>	<i>0.06</i>	<i>0.04</i>	<i>46.15% yes</i>
City centre	18.02	51.10	0.30	0.17	yes
Chaddlewood	8.40	2.01	0.06	0.03	No
Mutley	11.30	17.99	0.16	0.24	No

Although the rate of crime was not found to have a statistically significant association with overweight/obesity rates, the crime rate in the city centre which was identified as a hotspot is the highest compared to all other neighbourhoods. Similarly, the city centre has the highest density of fast food outlets. In contrast, in Chaddlewood, which was identified as a cold-spot for overweight/obesity, all available covariate values were below the respective average values. Mutley, a hotspot for both conditions, has no dental clinic but has the highest density of grocery shops.

5.9.4.1 Obesity and caries

There appears to be a weak relationship between caries rates and overweight/obesity rates at the neighbourhood level. This was identified by including overweight/obesity rates as a covariate in the spatial model for caries rates (which also corrects for heterogeneous population distribution between neighbourhoods). More specifically, one extra case (per unit population) of overweight/obesity in a neighbourhood, would increase the neighbourhood caries rate by 1.02 times (p-value 0.02). However, when covariates were controlled for in the model, the weak relationship between caries and overweight/obesity was masked by the relationship between the covariates and the response of interest (caries and/or obesity/overweight rates), and the relationship was no

longer significant. This was a result of confounding: There are covariates that are significant predictors for both obesity/overweight rates and for caries rates at neighbourhood level.

5.10 Discussion

The present spatial study has helped elucidate the impact of area and household deprivation on obesity and caries in Plymouth children. Through the application of a novel methodology, spatial clusters of the two conditions have been identified and possible explanations for the observed patterns are provided.

In the present study, IMD 2010 did not relate to children's weight status. Furthermore, no difference in the prevalence of overweight and obesity between children belonging to different Mosaic supergroups was observed. Our results showing an absence of an association between obesity and deprivation are consistent with some previous studies (Dummer et al., 2005; White et al., 1995) but the literature about the relationship is inconsistent (Shrewsbury & Wardle, 2008). Some studies have indicated a strong association between deprivation and obesity in children (Achat & Stubbs, 2014; Jansen & Hazebroek-Kampschreur, 1997; Marshall et al., 2007; Wu et al., 2015), whilst some others have even found a negative association between the two variables (Cernerud, 1994). One factor which should be taken considered for the inconsistent findings is the impact of age. For example, in an ecological study that was conducted using data from the National Child Measurement Programme, although IMD 2010 scores related to obesity rates in both age groups (4-5 years and 10-11 years) (Conrad & Capewell, 2012), deprivation related more strongly to obesity risk in the older children. Taking into account the stronger impact of deprivation on older children that has been found in the study of Conrad and Capewell (2012) and others (Kinra, Nelder & Lewendon, 2000), it could be that the young age of the participants in our study meant that deprivation may

have not yet had any impact on their weight. This may, at least in part, explain the lack of an association between increased weight status and deprivation measures in the present study. Furthermore, there have been various changes in children's lived environment in recent years, which may have resulted in an increased caloric intake and decreased expenditure in all SES groups (Anderson & Butcher, 2006; Conrad & Capewell, 2012), thus making it difficult to find differences in weight status among children from different SES backgrounds.

Our study showed no differences in weight z-scores of children living in areas with different levels of deprivation; however, children resident in more deprived areas were found to be shorter than children residing in less deprived neighbourhoods. This is consistent with the findings of Jansen and Hazebroek-Kampschreur (1997) who found that children living in poor neighbourhoods had slower growth compared to those living in more affluent neighbourhoods. This finding was also echoed by another study in which height and weight were measured among 23,046 Scottish children of different ages (3, 5, 7, 9, 11 and 14 years) and which showed that short stature was much more prevalent in older children from more deprived backgrounds (White et al., 1995). As height and weight-for-height are considered important indicators for health (Jansen & Hazebroek-Kampschreur, 1997; Tanner, 1989) and because height may be a better physical indicator of deprivation in urban areas (Cernerud, 1994), our findings appear to confirm previous suggestions that height may be a better index of childhood health than BMI or weight. The potential of using height as a predictor of dental caries was highlighted in a recent systematic review that examined the association between several anthropometric indicators and caries (Li et al., 2015a).

The current study showed a statistically significant relationship between deprivation and caries in children. Although the mechanism linking SES to dental caries has not yet

been fully elucidated, several suggestions have been made. Chen (1995) reported that individuals at low levels of SES have among other characteristics, more fatalistic beliefs with regard to oral health and perceive less need to utilise dental health care services. Price can also determine food choice (Darmon et al., 2014) and it has been shown that people from lower SES often choose to purchase foods which are high in fat and sugar as they are cheaper (Darmon & Drewnowski, 2008; Epstein et al., 2007); this can in turn impact on caries. Although these mechanisms could possibly be responsible for the link of deprivation to dental caries identified in our study, this cannot be confirmed by our study as data on the above elements were not collected. Other possible explanations by which SES could impact dental caries include differences in oral health behaviours, such as tooth brushing frequency as well as high intake of fruit/juices and/or soft drinks and low calcium intake (Hamasha et al., 2006; Jerkovic et al., 2009; Todd JE, 1985). These variables could not be investigated in this study.

In both datasets, children whose households were classified as Mosaic Supergroup A had better health outcomes in terms of prevalence of dental decay and average height z-score as compared to those who were Supergroup G. As mentioned previously, no associations were found between obesity and Mosaic Supergroups. Individuals in Supergroup A are commonly ‘middle income recipients’, while those in Supergroup G (‘young people renting flats in high density social housing’) are on limited incomes, suffer high levels of unemployment, are highly dependent on welfare benefits and purchase convenience food on a daily basis (Experian, 2009). Reports also suggest that cost and limited access to shops for individuals in Supergroup G may result in poor diet, as they cannot access quality fresh products (Experian, 2009). Even though it cannot be ascertained through the data, it could be that the relationship identified is mediated through unhealthy dietary patterns and the consumption of convenience food (which tends to be high in sugar and fat) associated with the particular supergroup. Furthermore,

given our findings which show a link between IMD 2010 and dental caries experience as well as height, these results confirm the impact of deprivation on both health parameters and also highlight the significant inequalities that exist amongst Plymouth children.

The mapping results showed significant variability in overweight/obesity and dental caries rates; however, some similarities in the distribution of the two conditions were also evident. High rates of both overweight/obesity and caries were located in neighbourhoods of South East and South West localities. The results further showed that the North West locality had high values of both obesity and caries rates and that caries prevalence increased from East to West of Plymouth. Consistent with the distribution of caries identified in the present study, a report by the Local Authority (Public Health Plymouth, 2013), revealed that the North West locality (which has been shown by our study to have the highest rates of children with caries) has the highest percentage of families that depend on state benefits (28.6% vs the Plymouth city average of 20.7%). Furthermore, in the Central and North East locality, which had the lowest caries rates in our study, the percentage of people dependent on benefits has been shown to be the lowest amongst all localities (18.4% vs 20.7% Plymouth average). Thus, it appeared that the distribution of caries in our population could be related to the percentage of people on state benefits that live in these areas. The spatial model confirmed that the percentage of people on benefits explains at least partly the spatial distribution of caries, thus reinforcing the idea that characteristics of the environment have an impact on the distribution of a health condition.

The presence of clusters of obesity and caries in particular areas indicates that these areas are somehow promoting risk for both conditions and that individual and environmental determinants may operate individually or act together to produce the

observed patterns (Pouliou & Elliott, 2009). It is acknowledged that people residing in adjacent areas tend to share similar lifestyles and that adjoining areas have similar environmental characteristics (Campos et al., 2011; Penney et al., 2014). It could therefore be that in adjacent areas that have been found to have similar rates of either condition in the present study, residents have similar behaviours/lifestyles that promote obesity and caries (e.g. high and frequent consumption of sugar, decreased physical activity). However, the impact of individual lifestyle factors on the observed patterns could not be examined in the spatial study as the analysis relied on extant data and information on the specific parameters mentioned was not collected. With regard to the neighbourhood characteristics, the only variable found by our analysis to have a significant impact on the caries rates was the number of people dependent on benefits. Although other studies have shown that the availability of unhealthy food outlets, rate of crime, density of grocery stores and presence of dental clinics (Cetateanu & Jones, 2014; Jennings et al., 2011) affect obesity or caries, this was not shown in the present work. It could be that relevant characteristics that were not examined in our study (i.e. availability of pavements, policies on food etc) were responsible for the observed patterns in Plymouth. In terms of the neighbouring locations with different rates of the two conditions, the mechanisms driving the emerging patterns are likely to be more complex (Penney et al., 2014). Before any prevention or intervention strategies take place, behavioural and environmental determinants contributing to the observed patterns ought to be more clearly understood.

Overall, the results of this spatial study highlight the association between deprivation and obesity and between deprivation and caries in Plymouth children and, most importantly, highlight the importance of geographically focused prevention strategies. The findings suggest that place itself has a role in the patterns that were identified and that further investigation is needed to explore the mechanisms that result in higher rates

of obesity and caries in the specific neighbourhoods. Taking into account evidence showing that the structural environment can have an effect on the development of health conditions, the impact of characteristics of the built environment on obesity and caries and their relationship should be examined in future studies. It is also important to note that although the current research focuses on the detection of high-risk areas, it may be valuable to investigate further areas of low risk as well (Pouliou & Elliott, 2009). In this way, it may be possible to identify factors contributing to the decreased risk of disease in the particular area.

5.11 Limitations

A number of limitations are pertinent in this study. Although the findings yield interesting information on the spatial patterns of childhood obesity and caries in Plymouth and the association of both conditions with deprivation, the present study is unable to identify all the factors contributing to the identified pattern nor show what lies behind any associations between the two conditions. Furthermore, as the samples examined consisted of different children, the association between excess weight and caries in individual children could not be directly examined.

The IMD 2010, which was used as the main measure of deprivation in the present study, assesses deprivation at the LSOA level and therefore it may not reflect the SES of the individual children per se (Kinra, Nelder & Lewendon, 2000). Despite this limitation, the IMD 2010 is considered the best means of making comparisons of different areas in England in terms of their deprivation (Conrad & Capewell, 2012). In the present study, Mosaic Public sector was used to supplement information from the IMD 2010 analysis. As Mosaic estimates deprivation at the postcode level, it can help distinguish levels of deprivation within an LSOA and can identify some elements of deprivation that may be

missed by the IMD (Experian, 2006). In addition, the present study looked at neighbourhood-level characteristics, which give more insight than IMD 2010.

Another weakness was the small sample size used for the spatial analyses which may have limited the ability to find any significant relationships between area-level covariates and obesity and caries.

Other weaknesses of this study relate to the cross-sectional analysis of the association between deprivation, weight status and dental caries which does not allow us to infer causation, despite the identified association between caries and deprivation.

Another limitation of the study is that positive parental consent was required for children's participation in the dental health survey. This may have underestimated the levels of caries in the population, as it has been reported that it is more difficult to obtain consent for children from less affluent backgrounds (Witton & Nelder, 2009). However, positive consent has been a national requirement since 2006 and our results show a good representation of children from less affluent backgrounds.

Furthermore, the study is limited by the existence of possible confounders which could not be accounted for, such as diet, gender (in the case of oral health survey), tooth brushing habits and others. Lastly, as with any other ecological analysis, we cannot reliably apply the findings of this ecological study at the individual level nor can we draw any conclusions about causal relationships.

5.12 Conclusions

Our findings revealed a significant geographical variation in the distribution of overweight/obesity and caries in Plymouth children. The study has also located spatial clusters of the two conditions. The findings reinforce the idea that policy makers and

other stakeholders should take into consideration the presence of spatial heterogeneity when developing prevention and intervention programmes.

The identification of 'hot spots' for both childhood overweight/obesity and dental caries can enable prevention and intervention strategies to target children at higher risk. Taking into consideration the distribution of caries among children in Plymouth and the impact of deprivation on the prevalence of the disease, priorities should be given to interventions in areas with the highest deprivation levels particularly those with a high number of people dependant on benefits.

The application of spatial analysis methods may provide useful information on areas of high risk and allow public health professionals and other stakeholders to take evidence-based decisions on the application of appropriate strategies that could target conditions simultaneously in an effective and efficient manner. However, in order to target obesity and caries effectively, more studies are needed to identify the individual and community-level factors and mechanisms contributing to the increasing prevalence of both conditions.

Chapter 6. Obesity and Caries in Plymouth Children

6.1 Introduction

In this thesis, the findings of the systematic review and the spatial analysis study were used as the foundation for developing the design for the school survey. From the systematic review, it was evident that there was a need to investigate the relationship between different measures of obesity and dental caries, and to examine how the relationship may be affected by several confounders. The ecological study indicated that geographic location and spatial heterogeneity impacted on the distribution of obesity and dental caries and highlighted the need to examine how several environmental features and characteristics, in addition to individual behaviours, may affect the distribution and possibly the association between the two conditions. That study also highlighted the need to examine the effect of deprivation, measured both at individual and geographical level, on caries and various obesity types.

6.2 Aims and objectives

The current study aimed to examine the relationship between different measures of obesity and dental caries in Plymouth children aged four to six years. The study also aimed to determine the association between individual health behaviours/characteristics and obesity and caries as well as the impact of neighbourhood-level characteristics on the two conditions.

6.2.1 Objectives of the survey

- To examine the prevalence of overweight, obesity and the prevalence and severity of caries among children in the reception year of schools in Plymouth.

- To examine the spatial distribution of childhood obesity and caries in Plymouth city and to identify spatial clusters of each condition.
- To investigate whether caries and obesity are associated, and if they are, to determine the direction and size of the effect.
- To determine whether different measures of obesity affect the association between excess weight and caries.
- To investigate the impact of deprivation on obesity and on caries at the LSOA, postcode and individual level.
- To examine the effect of several confounders on any associations found between obesity and caries.
- To investigate how individual behaviours and characteristics affect the distribution of obesity and caries in Plymouth children.
- To examine the effect of geographic location and environmental features on the spatial distribution of the two conditions.

6.3 Materials and methods

6.3.1 Study design

This was a cross-sectional study, conducted among children aged four to six years in the reception year of infant and primary schools in Plymouth.

6.3.2 Sampling and Participants

The sampling frame was all local state-maintained infant and primary schools in the city of Plymouth, Devon, UK. Special schools were not included, as it would be difficult for such schools to accommodate the study; their inclusion would also restrict the generalisability of the results to the general population. All the children attending the reception year of the selected schools, irrespective of their gender or nationality, were eligible for participation in the study.

In the 2014-15 academic year when the study was conducted, Plymouth had 66 schools (3 infant and 63 primary schools). A list of all infant and primary schools in Plymouth was obtained from Plymouth City Council. Based on the information obtained, the distribution of schools according to the localities was as follows (table 31).

Table 31. Plymouth infant and primary schools per locality

Locality	Number of schools
North West	15
South West	21
Central and North East	11
South East	6
Plympton	7
Plymstock	6

Sample size calculation was based on an observed odds ratio of 2.5 for the presence of dental caries ($dmft > 0$) in relation to high BMI (Alm et al., 2011). The schools invited to take part in the survey were selected through a random stratified procedure, using the six Plymouth localities as the strata. Twenty schools would need to be invited to participate in order to meet the target number of 352 children, which was estimated by a power calculation to give 80% statistical power at a 5% level of significance.

Taking into consideration the number of schools corresponding to each locality and the total number of schools that needed to be invited, the number of schools needed to be invited in each locality was calculated. The random sample of schools was selected using a random sample sequence generated with the R language.

The decision to use the six Plymouth localities as the strata for the study resulted from the spatial analysis in the ecological study which indicated a significant geographical variation in the distribution of the two conditions. Hence, it was important that all regions were represented in the sample. If simple random sampling had been adopted,

important parts of the population would potentially be missed (University of West England, Bristol, 2007).

6.3.3 Data collection

The fieldwork took place in the academic year 2014/15, and data collection was conducted between February to May 2015. The organisation and conduct of the survey was carried out in liaison with the Office of Public Health and the Educational Department of Plymouth City Council.

6.3.4 Preparation for the study-Training of the examiners

The researchers involved in the present study received training prior to the study according to established criteria in anthropometry and dental examination.

6.3.4.1 Anthropometric Measurements

The researcher (MP) obtaining the anthropometric measurements attended a three-day training course offered by the International Society for the Advancement of Kinanthropometry and met all requirements for accreditation as a technician (training and calibration). The course included training on all of the anthropometric measurements included in this study.

6.3.4.2 Dental examination

The dental examiner (RP) attended a training course on the methodology employed by the NHS Epidemiology Oral Health Survey of children aged 5 years (Pine, Pitts & Nugent, 1997) which uses the criteria of the British Association for the Study of Community Dentistry (BASCD) for the oral health examination (Pitts, Evans & Pine, 1997). The criteria included visual assessment of teeth that were decayed, missing or restored, as well as presence/absence of plaque and sepsis. Another researcher (KR) was trained in recording the results as per the BASCD criteria.

6.3.5 Pilot testing of study questionnaire

The study questionnaire that was filled out by the parents/guardians of the children aimed to obtain information on children's SES, their oral health behaviour and habits, and the frequency of consuming specific food items/beverages in between meals. It was pilot tested on 20 participants at Derriford and Devonport Dental Education facilities of Plymouth University. Subsequently, changes were made as per the participants' suggestions; the participants were parents/guardians of children visiting the dental facilities. The pilot testing took place between September 2014 and October 2014.

6.3.5.1 Aim

The pilot testing aimed to evaluate the acceptability of the questions and the response options included in the questionnaire and to examine whether the wording was clearly understood by the participants. It also investigated whether the questions were understood in the same way by all participants and enabled the researcher to assess the time needed for the participants to complete the questionnaire.

6.3.5.2 Procedure

When parents/guardians entered the Dental Education Facility and reported to reception, the receptionist informed them that a researcher from Plymouth University needed their help in testing a questionnaire. The receptionist also gave the parents/guardians a leaflet which informed parents of the survey's aims and that their decision to participate in the survey would not affect their child's treatment. The receptionist informed parents that a researcher would approach them shortly to ask them to help in testing a questionnaire about children's oral health and eating habits.

Once the parents/guardians were seated in the waiting room, the researcher (MP) approached them to describe the aim and procedure of the pilot study and to give them the information sheet and consent form. She also provided answers to any questions that

the parents/guardians had and emphasised that their decision to participate would not affect their child's treatment.

If the parents/guardians were willing to participate, they were asked to complete and sign the consent form. Thereafter, they were asked to fill in the study questionnaire and give their comments on the content, structure and comprehension of the questionnaire. At the completion of the pilot study, necessary amendments were made to the questionnaire.

6.3.5.3 Content

The first part of the questionnaire requested demographic information regarding the person who completed the questionnaire (parent/guardian), including their age group, how they were related to the child in question and their level of education. A question about the household's total income over the last 12 months was also asked; the categories used to classify the household's income were those used by the Office for National Statistics (Office for National Statistics, 2010) with some of them merged.

Questions on oral health behaviours and habits were obtained from the questionnaire used in the NHS Dental Epidemiological Oral Health Survey of five-year old English children in 2007/2008 (NHS, 2007). These focused on the frequency with which the child's teeth were brushed/cleaned, the age that the child first started having their teeth cleaned and whether an adult accompanied them while the teeth were brushed. The parents were also asked to provide information on their child's visit to a dentist in the last 12 months and if she/he had, they were asked to provide information on the reasons they had done so.

The last section of the questionnaire focused on the frequency with which children consumed sugary foods/beverages *in between meals* in the last week. The food

categories/subcategories used in the study's questionnaire were based on those used by the UK National Diet and Nutrition Survey which collects information on the population's nutritional status, nutrient intakes and food consumption (Department of Health and Food Standards Agency, 2011). The categories were slightly modified to suit what we needed to know with regard to caries development and included categories that have been found to be among the main sources of sugar in English children (Department of Health and Food Standards Agency, 2011).

Information on children's gender and ethnicity was obtained directly from the child's school administration. Parents provided their consent for this information to be obtained.

6.3.6 Recruitment procedure

Following the sampling of the schools, a letter was sent to the head-teacher of each selected school asking for their approval, support and co-operation for the study, and permission to contact the parents/guardians of the children attending the reception year at their schools was requested (appendix 7). The letter was accompanied by a support letter from Plymouth City Council, as they already had access to local schools through the National Child Measurement Programme.

Following the principals' approval, a letter/information sheet and a consent form were sent via the school, to the parents/guardians of all children in the selected year, outlining the details of the project and seeking their permission for their child's participation in the study (appendix 8). Thereafter, parents completed and signed the consent form (appendix 9) and returned it to the school. Following collection of the consent forms from the school, the study's pilot tested questionnaire (appendix 10) was sent to the parents asking to be returned on the assessment day. The procedure followed for the school survey is provided in Figure 16.

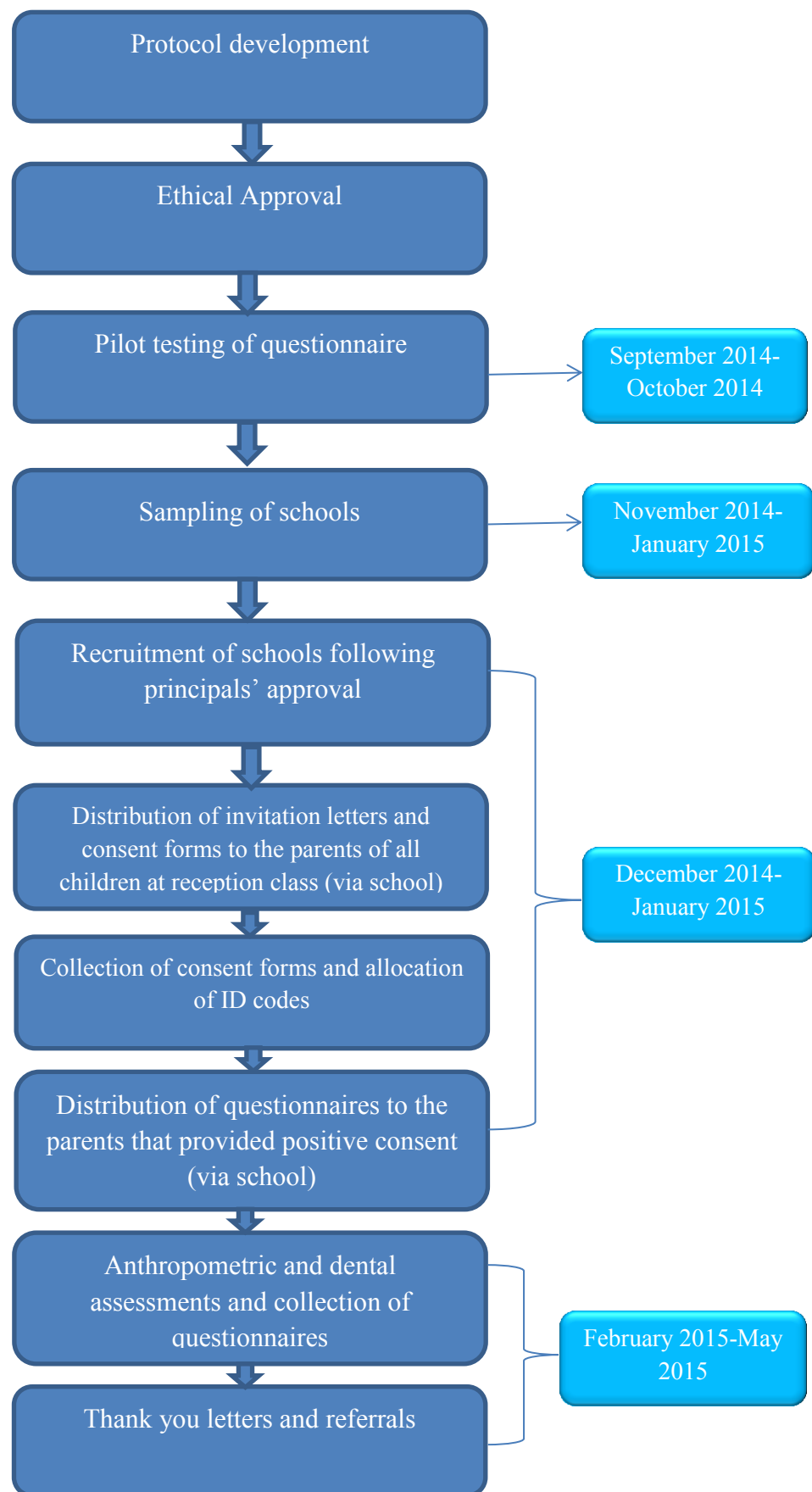


Figure 16. School survey procedure

6.3.7 Field work

The assessments of weight status and dental caries were conducted in a private room at the school premises to ensure the participants' confidentiality and privacy; the examinations took place at a date and time that were most convenient for the school. On the day of the assessment, children were briefed on the measurements that would follow. If for any reason, full measurements were difficult to achieve (for example in children with physical disabilities or with a medical condition that hampered their ability to stand on weighing scale and height measures), this was noted on the data collection form. Missing data were treated appropriately in the analyses.

Extra care was taken to ensure that the children felt comfortable taking part in the study. If they did not, the child was able to withdraw from the study even if his/her parent/guardian had consented for his/her participation. Under no circumstance was a child coerced into taking part in the study. Parents were also given the opportunity to attend the assessment if this was agreed by the school's principal.

6.3.7.1 Clinical examinations

6.3.7.1.1 Assessment of anthropometric measures

The anthropometric measures included in this study were weight, height, waist and hip circumference and triceps skinfold thickness. These were obtained by a trained researcher using established procedures (International Society for the advancement of Kinanthropometry: (ISAK), 2001; Lohman & Going, 1998) and with participants in no shoes and with light clothing. Measurements were taken twice, and in the case of disagreement between the readings, a third measurement was taken and the mean of the two closest values was taken. Details of the individual measurements are provided below.

- **Weight**

Weight was measured in kilograms to two decimal places with an 877 Seca Electronic personal scale (with two in one weighing). The children were asked to stand in the centre of the scale with their feet together and stand still, looking ahead. The recording was obtained three seconds after the child stood still.

- **Height**

Height was assessed with a Seca 217 stadiometer to the closest 0.001 meters. The children were asked to stand with their feet flat and together, and their heels against the rod at the centre of the base plate. They were also asked to relax their arms and straighten their back. Their head was placed in the Frankfort Plane position and a gentle pressure was applied on either side of their chin, in order to stretch the child to their maximum height after they breathed in; the recording was obtained at this stage.

- **BMI**

From the weight and height, the standard formula was used to calculate children's BMI. Definition of children's weight status was based on the UK 1990 growth reference centiles which are age and gender specific (Cole, Freeman & Preece, 1995). For the classification of children to the different weight categories, the cut points used in population monitoring were used. The 'LMS Growth' Microsoft Excel add-in software (Cole & Green, 1992; Pan & Cole, 2012) was used to assign children to the corresponding percentiles and z-scores.

The use of national and not international reference data was based on the fact that this approach has been recommended by expert Committees including the National Institute for Health and Care Excellence (NICE) and the Scottish Intercollegiate Guidelines Network (SIGN) (National Institute for Health and Care Excellence, 2014; Scottish Intercollegiate Guidelines Network, 2010b). Furthermore, there is no evidence that the

use of the international reference data has any advantage over the use of the national data (Reilly, 2002) and the advice is to utilise national reference data wherever possible.

A study in the UK examining the sensitivity of IOTF International classification system against the UK BMI curves classifying obesity, found that the current national definition showed a much higher sensitivity and specificity than the international one when defining obesity in seven-year old children, particularly boys (Reilly, 2002). Another study in the UK, found that the international classification system exaggerated the gender difference in overweight and obesity prevalence in English children, when compared to the 1990 national reference data (Chinn & Rona, 2002). The cut-off points used for population monitoring used in the current study are slightly lower than the clinical ones, and can therefore help identify children who have a weight problem or are at risk of developing one.

- **Waist and Hip circumference**

Waist and hip circumference were measured to the nearest centimetre, using the Bodymorph melastic tape. Waist circumference measurement was taken between the lowest rib and the highest border of the iliac crest, with the tape being perpendicular to the floor. The measurement was recorded at the end of a normal expiration.

Hip circumference measurement was taken at the greatest posterior protraction of the gluteal muscle with the tape horizontal to the floor. Children were asked to keep their arms folded across their chest.

- **Triceps skinfold**

TRSKF was assessed on the right arm by a Harpenden skinfold caliper (HSK-BI) to the nearest 0.1 millimetre. The children were asked to relax and the skinfold was obtained where the mid-line of the posterior surface of the arm meets the projected mid acromiale-radiale perpendicular to the arm's long axis. The caliper was held at 90

degrees to the surface of the skinfold site and a measurement was obtained two seconds after the full pressure of the caliper was applied (after grasping and lifting the skinfold).

6.3.7.1.2 Oral health examination

The prevalence and severity of caries in the sample was examined using the dmft index, following the methods and criteria recommended by BASCD (Pitts, Evans & Pine, 1997) and also employed in PHE's Dental epidemiology programme for five year olds. Radiographs were not taken. The SiC Index was also used to assess the experience of dental caries in the sample (Bratthall, 2000). For the visual-only examination, the examiner used intra-oral disposable mouth mirrors, a standardised light source (Daray light) and disposable gloves. Children were examined by one examiner who was seated behind the child. A data recorder was also present during all measurements.

In order to assess intra-examiner reliability for caries, 10 % of the sample (N=35) was randomly selected for repeat measurements. The percentage intra-rater agreement for presence/absence of caries was 100% ($p=0.000$). The κ statistic for caries was 0.94 ($p<0.001$) which indicates an almost perfect agreement (Cohen, 1960; Landis & Koch, 1977).

6.3.7.4.3 Rewards

Following the anthropometric and dentition status assessments, children were given a sticker and a participation certificate on the day of the examination. A separate certificate of appreciation was also sent to the schools as a gesture of appreciation for their support and participation in the study.

6.3.8 Ethical considerations

6.3.8.1 Debriefing-Referrals

Parents/guardians were invited to allow their children to take part in the survey through an invitation letter/ information sheet specifically developed for the purpose of the study. A consent form was also included in the initial communication pack. The invitation letter provided details about the purpose and procedures of the study and contained the contact details of the research team in case any further information was required.

Following completion of data collection, a 'thank you' letter (appendix 11), as well as leaflets and a poster on dental health and healthy eating were sent directly to the children's parents/guardians via post. If the dental condition of a child required further investigation, this was indicated in the feedback letter and parents had the opportunity to make an appointment at Derriford or Devonport Dental Education Facility of Plymouth University, Peninsula Schools of Medicine & Dentistry if they wished (appendix 12). In these this case, the letter was marked 'Private and Confidential'.

Children who were found to be above the healthy BMI centile were not referred to any support centre, as they would most likely be identified through the NCMP which was to take place in the same period as our study. This decision was based on a recommendation from the Public Health Consultant of Plymouth City Council who leads the implementation of NCMP in Plymouth, and a mutual agreement between the research team and Plymouth City Council.

6.3.8.2 Confidentiality

Data were handled in accordance with Data Protection Legislation; all the necessary steps were undertaken to ensure that the confidentiality and anonymity of the

participants' were safeguarded throughout the conduct of the research and the reporting of the results. The participants were given a study code and results obtained from individual participants were analysed in reference to their allocated codes. No individual results were given to the school or any other authority other than the parents/guardians of the children whose children's dental condition required further investigation.

The principal investigator and the educational director are the only people who have access to the personal data. The computer containing the study data and access to all data files is password-protected. Hard copies of the primary research data are held in a locked cupboard at Plymouth University. All primary research data (consent forms and individual results on papers sheets) will be held securely at the University of Plymouth for 10 years, after which they will be destroyed.

6.3.8.3 Right to withdraw

Parents/guardians were informed (via the invitation letter and the consent form) that their child's involvement in the study was completely voluntary. They were also informed that even if they consented to their child's involvement in the study, they were entitled to withdraw him/her at any time, without there being any consequences. It was also made clear that there would be no need to provide any explanation for such a decision. This was clearly stated on both the information sheet/invitation letter and the consent form that was sent to children's parents/guardians. The information sheet also contained the contact details of the research team. It was decided *a priori*, that if a parent chose to withdraw their child after the data collection was completed, then the corresponding data (both the hard copies and the electronic ones) would be destroyed. In addition, children were informed that they were free to withdraw on the day of the examination if they wished.

6.3.8.4 Protection from harm

The children in this study were vulnerable because of their young age, as well as their physical (and legal) dependency upon adults. Although there was very low risk of physical harm or pain to the participants (e.g. dental examination was almost a non-touch procedure), children can be sensitive when it comes to their anthropometric measurements taken. Although this is more common in older children, all measurements were taken sensitively by the research staff and extra care was given if any anxieties arose or if children showed signs of dislike of the process. If any child required particular attention, a teaching assistant continually accompanied and encouraged them during the assessments.

The research team ensured that the privacy and confidentiality of the children assessed were fully protected and that children understood that their involvement in the study was totally voluntary. They also ensured that the children understood that their decision to take part or not in the study would have no positive or negative impact on their school life and that they could withdraw at any stage without there being any consequences. In case there was a dental condition which required further investigation, the letter was posted directly to the parents (and not via the children), to ensure that the results did not get into the hands of other children leading thereby to potential stigmatising and the possibility of bullying.

6.3.8.5 Openness and honesty

The contact details of the principal investigator and the Director of Studies were provided in the information sheet given to the parents/guardian before the study. The parents/guardians were given the opportunity to contact the research team before and after data collection via post, email or telephone. The research team were also happy to answer any questions on the day of examination. Parents were also given the

opportunity to be present when their child was being measured, provided that the school agreed. Both the parents/guardians and the children had all of their queries regarding the study, its purpose, results and application answered in an open and honest way. If parents wished, the anthropometric results for their child were also posted to them.

6.3.8.6 Route for complaints

If the parents/guardians had any concerns about the study, they were given the opportunity to contact the educational director and/or the administrator of the Faculty Human Ethics Committee, Plymouth University. Their contact details were provided to the parents/guardians via the invitation letter.

6.3.8.7 DBS/CRB checks

As the current research involved children, all researchers that were involved in the field work provided their DBS/CRB clearance to the Senior Administrator (Research Degrees) of Peninsula College of Medicine & Dentistry prior to the onset of the survey.

6.3.8.8 Ethical Approval

The study (including the pilot testing of the questionnaire) was approved by the Faculty of Health and Human Sciences Research Ethics Committee of Plymouth University (*Reference number: 13/14-240*) (appendix 13). No ethics approval was required from the National Health Service, as the participants were not recruited through any of their sites.

Information on IMD 2010, Mosaic Public Sector Groups and environmental features at the local level were provided by Plymouth City Council. Although no ethics approval was required for the release of this information, the Director of Studies organised an agreement policy (Third Party Use of Resources) to be signed between Plymouth University and Plymouth City Council at the beginning of this project.

6.3.9 Statistical methods

The IMD 2010 was used as a measure of area deprivation and the Mosaic Public Sector as a complementary measure of deprivation. The IMD quintiles were merged into three categories for the purpose of several statistical tests.

6.3.9.1 Statistical analyses

Continuous and categorical variables are presented as means (\pm SD) and frequencies (%), respectively. The association of deprivation (IMD 2010-continuous variable) with anthropometric variables (weight height, BMI, waist and hip circumference, waist to hip ratio and triceps skinfold-continuous variables) and dmft scores (counts) was determined using the ANOVA and Poisson regression models, respectively. ANOVA was used to compare the children's BMI, height, and weight among the different Mosaic Supergroups, together with the Bonferroni adjustment for multiple comparisons. Poisson regression was used to examine the difference in average dmft scores between the Mosaic Supergroups.

Differences in tooth brushing frequency (once or less per day vs ≥ 2 times per day) were examined using a logistic regression model with IMD categories (IMD-1,2,3), income (up to £25.599, 26.000-36.399, 36.400 and above) and education (up to secondary school, Technical/College, University) included as covariates in the model. The relationship between anthropometric variables (weight, height, BMI, waist and hip circumference, W/H ratio) and dental caries experience as indicated by dmft (dmft >0), was examined using Multiple logistic regression. Logistic regression was used to test differences in the response rate (for the questionnaires) between parents/guardians living in areas with different levels of deprivation (IMD-1, 2 or 3).

For all models, a three-step procedure was followed. First, exploratory analysis was performed. In the cases where both the response and the available covariates were

continuous, this included getting the summaries of all variables, as well as producing scatterplots of the response against all available covariates. Where the scatterplots suggested a linear relationship between the response and the covariate(s), but also for the ANOVA model, the response was assessed for normality employing histograms and the Shapiro-Wilk test. Confirmation of normality of a continuous response led to fitting linear models when all the covariates were continuous and ANOVA models when all the covariates were categorical. For binary responses logistic regression was employed, whereas Poisson regression was used for count data. In the latter case, the exploratory analysis included obtaining summaries of the responses (e.g. proportions in each category for logistic regression) and assessment of the distribution of the response with respect to the available covariates. In all cases, following model fitting, the model fit was assessed using suitable diagnostic measures (e.g. the R-squared and residuals for linear regression, as well as residuals). Finally, significance tests to assess the model adequacy were performed, before assessing the significance of the covariates included in each model (reported for each model separately in what follows).

6.3.9.2 Spatial statistics

For the purpose of spatial analyses, the Global Moran's I statistic and the LISA were used to assess global clustering and to identify local clusters, respectively. Information on the two statistics is provided in Chapter 5.

6.3.9.3 Neighbourhood level factors

A spatial dependence model was used to examine the association between obesity and caries at the neighbourhood level: Generalised linear models (log-linear Poisson models) were used to assess the significance of the several covariates (environmental features) on the rates of overweight/obesity and/or dental caries at neighbourhood level. The covariates included were:

1. Number of people on Benefits; converted to percentage of people on benefits in each neighbourhood.
2. Number of Crimes; converted to a percentage (per unit population).
3. Number of Fast food outlets; converted to a percentage (per unit population).
4. Number of Grocery shops; converted to a percentage (per unit population).
5. Number of Dental clinics; converted to a binary variable: dental clinic(s) present in neighbourhood/ dental clinic(s) not present in neighbourhood.

All were adjusted for the population in each neighbourhood. IMD was not considered as a covariate at neighbourhood level, because it is recorded at LSOA level and because some of the covariates examined are included in the calculation of IMD. The initial model included all available covariates listed above. Then starting with the least significant covariate (based on p-value) and using backwards elimination, the covariates were removed from the model one-by-one. Each time a covariate was removed, the model was refitted. This process was repeated until only significant covariates were left in the model (all with p-values > 0.05).

6.3.9.4 Individual-level factors

The impact of several demographic factors and individual health behaviours on caries (binary variable: yes or no) and/or obesity/overweight (binary variable: yes or no) was also examined. In the above mentioned models, covariates were inserted one by one using stepwise regression (i.e. combining backward elimination and forward selection, allowing for covariates removed early in the process of backwards elimination to be reconsidered at a later stage).

Demographic factors included in the model were the parent's age group (<30 years vs >30 years) and education (up to secondary school, Technical/College, University), the family's total income (up to £25,599, 26,000-36,399, 36,400 and above), and the

gender of the child. Individual behaviours examined included were tooth brushing habits (once or less per day vs ≥ 2 times per day), age when the child started having his/her teeth cleaned (< 1 year vs > 1 year), presence of adult with children when teeth are being brushed (yes vs no) and frequency of in between meals food/drink consumption (using never as a reference). Logistic regression models with response ‘the presence/ absence of dental decay’ and ‘being/not being obese overweight’ were fitted.

The mapping and the spatial analysis were conducted using the shape files of the boundaries of neighbourhoods. Results of the spatial analysis are discussed at LSOA, neighbourhood and locality levels.

The Statistical Package for the Social Sciences (SPSS, ver. 21; SPSS Inc, Chicago, IL, USA) and the R software environment were used for the analyses. Small p-values (less than 0.05) suggested a significant effect/difference.

6.4 Results

Details on the recruitment procedure are presented in Appendix 14. Overall, the parents of 378 children from 14 schools agreed to their child’s participation in our study. Of these, 19 children were absent and another four had already left the school when the assessment took place. Furthermore, one child refused to have a dental examination and six (including the one which refused dental examination) did not want to have their triceps skinfold measured.

Thus, data on anthropometry and dental health were available for 349 and 354 children respectively, so data on both anthropometry and oral health was available for 349 children. The results that follow relate to these 349 children.

6.4.1 Descriptive characteristics

The total sample included 349 children aged 5.10 ± 0.31 (mean \pm SD). There were 50.1% (N=175) boys and 49.9% (N=174) girls. The majority of children were of white background (N=323, 92.6%) while the second most prevalent ethnicity was that of mixed background (N=9, 2.6%). Further details on ethnicity distribution are presented in Table 32.

Table 32. Ethnicity distribution of children in the sample

Ethnicity	Frequency (n)	Percentage %
White	323	92.6
Mixed	9	2.6
Asian or Asian British	5	1.4
Chinese	1	0.3
Any other ethnic group	3	0.9
Unknown	5	1.4
Total	349	100

The descriptive statistics for the anthropometric measurements are presented in Table 33.

Table 33. Summary statistics for anthropometric measurements

Anthropometric measurements	Mean	SD	Min	Max
Weight (kg)	19.58	2.76	13.70	32.30
Height (cm)	109.87	5.13	94.40	124.40
BMI (kg/m ²)	16.16	1.36	13.20	23.44
Waist (cm)	54.01	3.13	47.20	67.90
Hip (cm)	59.91	3.74	51.50	74.80
Triceps (mm)	10.70	2.83	5.80	19.90

6.5.2 Prevalence of overweight and obesity

The children's BMI classification categories are presented in Table 34. The majority of the children in the sample (N=279, 79.9%) were found to be in the healthy-weight category for their age and gender, while 19.5% (N=68) in total were found to have

excess weight (either overweight or obese). Only two children were underweight and this comprised 0.6% of the study sample.

Table 34. BMI distribution of children

BMI category	Frequency (n)	Percentage (%)
Underweight	2	0.6
Healthy weight	279	79.9
Overweight	38	10.9
Obese	30	8.6
Total	349	100

6.4.3 National comparisons

When our study's results were compared with those of the NCMP 2014/15 (Lifestyles Statistics Team: Health and Social Care Information Centre, 2015), the prevalence of healthy weight children in our sample was shown to be above the national average (79.9% as compared to 77.2%) (table 35). The prevalence of overweight and obese participants was below the national average (10.9 % as compared to 12.8% and 8.6 % compared to 9.1 %, respectively), as was the case with the number of underweight children (0.6% compared to 1.0 %).

Table 35. National comparisons of BMI distribution

	Underweight (%)	Healthy (%)	Overweight (%)	Obese (%)
Plymouth	0.6	79.9	10.9	8.6
England*	1.0	77.2	12.8	9.1

6.4.4 Distribution of children by national quintile of deprivation

As shown in Table 36, the majority of the children in the sample (N= 107, 30.7%) were found to reside in the most deprived areas of Plymouth. It appears that as the national quintile increases, and therefore deprivation decreases, the number of children falling in the least deprived categories decreases.

Table 36. Distribution of children by national quintile of deprivation

National Quintile	Frequency (n)	Percentage (%)
1	107	30.7
2	73	20.9
3	55	15.8
4	52	14.9
5	50	14.3
Missing	12	3.4
Total	349	100

6.4.5 Mosaic Public Sector

6.4.5.1 Mosaic Groups

Table 37 displays the distribution of children in our sample to the different Mosaic groups (MAST, 2014a).

The most common Mosaic Public Sector group that children belonged to according to their household postcodes was M-‘Family Basics’ (18.3%), which includes families with school age children and parents aged 25-40 who have limited resources and budget (household income: <£15k). The next most prevalent Mosaic group was H-‘Aspiring homemakers’ (15.5%), which are younger households and the majority are in full time employment (household income: £40k-49k) living in houses priced within their capabilities. The third most common group in the sample was L-‘Transient Renters’ (11.7%), at which individuals commonly choose low cost housing for the short –term and have a household income of £20k-29k.

Group B-‘Prestige positions’, which are ‘established families that live in large houses and in upmarket lifestyles’, and group I-‘Urban cohesion’, that are ‘residents of settled urban communities with a strong sense of identity’, were the categories that were least represented in the study sample (2.3% and 2.6%, respectively).

Table 37. Distribution of the Sample by Mosaic Groups

Mosaic Group	Frequency (n)	Percentage (%)
B Prestige Positions	8	2.3
D Domestic Success	16	4.6
E Suburban Stability	24	6.9
F Senior Security	24	6.9
H Aspiring Homemakers	54	15.5
I Urban Cohesion	9	2.6
J Rental Hubs	25	7.2
K Modest Traditions	27	7.7
L Transient Renters	41	11.7
M Family Basics	64	18.3
N Vintage Value	24	6.9
O Municipal Challenge	21	6.0
NA	12	3.4
Total	349	100

6.4.5.2 Mosaic Types

Table 38 shows the representation of Public Sector Types (MAST, 2014b) in the study sample.

The three Mosaic types that were most highly represented in our sample were: 1) M55- ‘Families with needs’ (10%) who ‘have many children, live in highly deprived areas and need support’, 2) H35-‘Primary ambitions’ (6.9%) who are ‘younger families who sought affordable places in good suburbs’ and 3) L52-‘Midlife Stopgap’ (6.3%) that are ‘maturing singles who are employed and are renting low-cost houses for the short-term’ (MAST, 2014b).

Table 38. Mosaic Types distribution in the sample

Mosaic Type	Frequency (n)	Percentage (%)
M55 Families with Needs	35	10.0
H35 Primary Ambitions	24	6.9
L52 Midlife Stopgap	22	6.3
M53 Budget Generations	17	4.9
O63 Streetwise Singles	15	4.3
F25 Classic Grandparents	12	3.4
K46 Self Supporters	12	3.4
K47 Offspring Overspill	12	3.4
N57 Seasoned Survivors	12	3.4
E20 Boomerang Borders	11	3.2

6.4.6 Distribution of BMI by deprivation group of residence

Table 39 presents the BMI distribution in the sample by deprivation, as determined by the IMD 2010.

Overall, the majority of children in the sample fall within the 1st IMD national quintile (N=180, 53.7%), which represents the most deprived areas. The children who were found to be obese were mostly found to be living in the most deprived areas of Plymouth (66.7% vs 23.3% who lived in the least deprived areas). Similarly, overweight was more than doubled in the most deprived areas (56.8% vs 21.6% in the least deprived areas). Lastly, healthy-weight children were mostly residing in the most deprived areas, however, the difference between the least and most deprived areas was not as large as that observed for overweight and obese children.

Table 39. BMI distribution by IMD national quintile

IMD National Quintile	BMI centile categories			Total
	Obese	Overweight	Healthy	
1 (n, % within BMI category)	20 66.7	21 56.8	139 51.9	180 53.7
2 (n, % within BMI category)	3 10	8 21.6	43 16	54 16.1
3 (n, % within BMI category)	7 23.3	8 21.6	86 32.1	101 30.1

6.4.7 Distribution of BMI by gender

When gender distribution among the different weight categories was examined through cross tabulation, it was found that no difference existed between the two genders in any of the categories (df=2, p=0.726) (table 40).

Table 40. BMI distribution by gender

	BMI centile categories			Total
	Obese	Overweight	Healthy	
Girls (n, % within gender category) % of total sample	14 (8.1) 4	17 (9.8) 4.9	142 (82.1) 40.9	173 49.9
Boys (n, % within gender category % of total sample)	16 (9.2) 4.6	21 (12.1) 6.1	137 (78.7) 39.5	50.1

6.4.8 Oral Health Results

The children in the sample had on average 1.01 ± 2.07 (0.79-1.23) (mean dmft \pm SD & 95% CI) teeth affected by caries. The mean number of teeth that were decayed among the participants was 0.86 ± 1.82 (0.67-1.06) (mean dt, SD and 95% CI) and the mean number of missing teeth was $0.06 \pm .47$ (0.01-0.11) (mean mt, SD and 95% CI). Overall, an average of 0.08 teeth ± 0.13 (0.04-0.13) (mean ft, SD and 95% CI) in the total sample were found to have been restored.

Of the total sample, 110 children (31.7%) were found to have caries experience as indicated by a dmft score above zero (dmft>0). These children had on average 3.18 teeth affected by decay (3.18 ± 2.574) (2.70-3.67) (mean dmft \pm SD and 95% CI).

One hundred and five children (N=105, 30.26%) had active dental decay (dt>0) and these children had on average 2.86 ± 2.306 (2.41-3.30) affected teeth (mean dt, SD and 95% CI). The SCI in the sample was 3.02.

6.4.8.1 Distribution of decay by gender

Cross tabulation results (table 41) showed that there was no difference between genders in terms of the presence of decay (dmft>0) (df=1, p=0.818).

Table 41. Prevalence of decay by gender

	No decay	Presence of decay	Total
Girls (n, % within gender category) % within presence of decay	117 (67.6) 49.4	56 (32.4) 50.9	173 (100) 49.9
Boys (n, % within gender category) % of total sample	120 (69) 50.6	54 (31) 49.1	174 (100) 50.1

6.4.8.2 Presence of decay by deprivation group of residence

Table 42 shows the distribution of dental caries in the sample by deprivation group of residence. The majority of children who had dental caries experience resided in the most deprived areas of Plymouth (IMD-1, 64.8%). Only 19.4% of children with active decay were resident in the least deprived areas. In the children who had no decay the difference was smaller (48.5% in IMD-1 vs 35.2% in IMD-3).

Table 42. Prevalence of decay by IMD category

IMD category	Decay No	Decay Yes	Total
1 (n, % within IMD categories, % presence of decay)	110 61.1 48.5	70 38.9 64.8	180 100 53.7
2 (n, % within IMD categories, % presence of decay)	37 68.5 16.3	17 31.5 15.7	54 100 16.1
3 (n, % within IMD categories, % presence of decay)	80 79.2 35.2	21 20.8 19.4	101 100 30.1

Children resident in the most deprived areas of Plymouth had 1.29 teeth on average affected by caries (dmft =1.29, SD=2.3) compared to those in the least deprived areas who had 0.45 teeth on average affected by decay (dmft=0.45, SD=1.14).

Children with some experience of caries (dfmt>0) resident in the most deprived areas of Plymouth, had 3.33 teeth on average affected by decay (dmft=3.33, SD=2.7). Children resident the least deprived areas, had on average 2.14 teeth affected by caries (dmft=2.14, SD=1.7).

6.4.9 Questionnaire results

From the total of 378 children (before exclusions), questionnaires were not returned for 99 children (26%), yielding a response rate of 74%. The results of the replies to the various questions included in the study's questionnaire are presented below.

❖ Parent's age (n, %) (table 43)

The most common age range of the parent/guardian completing the questionnaire was 30-39 years of age (n=152, 43.8%).

Table 43. Age groups of parents/guardians completing the questionnaire

Age groups	Frequency (n)	Percentage (%)
Less than 20	1	0.3
20-29	52	15.0
30-39	152	43.8
40-49	51	14.7
50+	2	0.6
Missing	89	25.6
Total	347	100

❖ Relation to the child (N, %) (table 44)

The completed questionnaires that were returned were most commonly completed by the mother of the child (N=240, 93%).

Table 44. Relation of the person completing the questionnaire to the child

Relation	Frequency (n)	Percentage (%)
Mother	240	69.2 (93)
Father	17	4.9 (6.6)
Grandmother	1	0.3 (0.4)
Missing	89	25.6
Total	347	100

❖ **Highest level of education the parent/guardian achieved (N, %) (table 45)**

As shown in Table 46, just over half of the parents/guardians had completed technical school/college or university level (N=185, 53.3%) and only 17.3% had completed either primary (N=3, 0.9%) or secondary education (N=57, 16.4%).

Table 45. Educational attainment of parents/guardians completing the questionnaire

Level of education	Frequency (n)	Percentage (%)
Primary school	3	0.9
Secondary school	57	16.4
Technical school/College	96	27.7
University	89	25.6
Other	9	2.6
Missing	93	26.8
Total	347	100

❖ **Household total income (N, %) (table 46)**

Of the parents/guardians who chose to answer this question, the majority (N=86, 24.8%) indicated that the total household income was between £5,200 to £25,599, which was the second-lowest category.

Table 46. Children's household total income

Income categories (£)	Frequency (n)	Percentage (%)
Up to 5,199	8	2.3
5,200-25,599	86	24.8
26,000-36,399	46	13.3
36,400-51,999	54	15.6
52,000 and above	31	8.9
Prefer not to answer	27	7.8
Missing	95	27.4
Total	347	100

❖ **Times child's teeth brushed (N, %) (table 47)**

The majority of parents/guardians (N=204, 58.8%) reported that their children's teeth were brushed two times a day, while none of the children were reported to never have their teeth brushed.

Table 47. Children's tooth brushing frequency

Tooth brushing frequency	Frequency (n)	Percentage (%)
Never	0	0
Less than once a day	3	0.9
Once a day	45	13.0
Twice a day	204	58.8
Three times a day or more	1	0.3
Missing	94	27.1
Total	347	100

❖ **Age when child first started having their teeth cleaned (N, %) (table 48)**

Based on the parents/guardian replies, most of the children (N=158, 45.5%) started having their teeth cleaned below the age of one year. The next most numerous group started brushing their teeth between one to two years (N=78, 22.5%).

Table 48. Distribution of children based on when they first started brushing teeth

Age groups	Frequency (n)	Percentage (%)
Under 1 year	158	45.5
1-2 years	78	22.5
2-3 years	10	2.9
3 years or over	1	0.3
Cannot remember	6	1.7
Missing	94	27.1
Total	347	100

❖ **Adult accompanying a child when brushing teeth (N, %) (table 49)**

Asked whether an adult accompanied their child while they brushed their teeth, the majority of parents (N=232, 66.9%) responded positively.

Table 49. Adult accompanying a child while brushing teeth

Responses	Frequency (n)	Percentage (%)
Yes	232	66.9
No	21	6.1
Missing	94	27.1
Total	347	100

❖ **Visit to dentist in the last 12 months (N, %) (table 50)**

Over half of the responders (N=203, 58.5%) indicated that their child had visited a dentist in the last 12 months.

Table 50. Visit to the dentist in the last year

Responses	Frequency (n)	Percentage (%)
Yes	203	58.5
No	51	14.7
Missing	93	26.8
Total	347	100

❖ **Most common reason for visiting dentist (N, %) (table 51)**

For the children whose parent/guardian reported that they had visited the dentist in the last 12 months, the most common reason reported was that the parents knew that a routine check-up was due (N=154, 44.4%) or that the dentist had sent the parent/guardian a reminder (N=35, 10.1%). Five parents/guardians (1.4%) reported that their children had visited the dentist because they had toothache or some other problem.

Table 51. Reasons for visiting the dentist

Responses	Frequency (n)	Percentage (%)
Knew a routine check-up was due	154	44.4
The dentist sent parent/guardian a reminder	35	10.1
The school dentist sent a note home suggesting a check up	1	0.3
Child had toothache or some other problem	5	1.4
Check up and reminder (1&2)	7	2.0
Check-up and toothache (1 & 4)	1	0.3
Missing	144	41.5
Total	347	100

❖ **In between meals food/beverages consumption (N, %) (table 52)**

Table 53 displays the frequency of in-between meals consumption of various food and beverages. Fruit and fruit drinks were the food items/beverages most frequently consumed between meals among the participants.

More specifically, 11.5% (N=40) and 15% (N=52) of the children respectively, were reported to consume fruit and fruit drinks, three times or more per day. Puddings, sugars, syrups, sweet spreads and sugared/regular soft drinks were reported as never being consumed for 32.9% (N=114), 36.9% (N=128) and 58.2% (N=202) of the children in the sample, respectively.

Table 52. Frequency of consumption in between meals

Food category	Never (n, %)	Less than once a day (n, %)	1 time/day (n, %)	2 times/day (n, %)	3 times or more/day (n, %)	Missing (n, %)
Sugar confectionary	37 (10.7)	139 (40.1)	74 (21.3)	5 (1.4)	1 (0.3)	91 (26.2)
Chocolate confectionary	15 (4.3)	148 (42.7)	83 (23.9)	10 (2.9)	0	91 (26.2)
Biscuits	44 (12.7)	120 (34.6)	77 (22.2)	10 (2.9)	2 (0.6)	94 (27.1)
Cakes, pastries and fruit pies	91 (26.2)	138 (39.8)	25 (7.2)	1 (0.3)	0	92 (26.5)
Puddings	114 (32.9)	104 (30)	34 (9.8)	2 (0.6)	1 (0.3)	92 (26.5)
Yoghurt and other dairy desserts	29 (8.4)	60 (17.3)	123 (35.4)	41 (11.8)	1 (0.3)	93 (26.8)
Breakfast cereals	61 (17.6)	37 (10.7)	150 (43.2)	8 (2.3)	0	91 (26.2)
Sugars, Syrups, sweet spreads	128 (36.9)	77 (22.2)	41 (11.8)	7 (2.0)	3 (0.9)	91 (26.2)
Fruits	11 (3.2)	19 (5.5)	83 (23.9)	104 (30)	40 (11.5)	90 (25.9)

Fruit juice	82 (23.6)	66 (19)	69 (19.9)	25 (7.2)	14 (4.0)	91 (26.2)
Fruit drinks	46 (13.3)	48 (13.8)	55 (15.9)	56 (16.1)	52 (15.0)	90 (25.9)
Sugared/regular soft drinks	202 (58.2)	45 (13)	6 (1.7)	2 (0.6)	1 (0.3)	91 (26.2)
Sugar milk based beverages	108 (31.1)	100 (28.8)	38 (11)	8 (2.3)	1 (0.3)	92 (26.5)

6.4.10 Statistical Analysis

6.4.10.1 Anthropometrics and IMD

When the relationship between all anthropometric indices and IMD 2010 was examined in a linear regression model, it was found that IMD 2010 had a significant impact on BMI only ($p=0.016$). More specifically, a 10 unit increase in IMD 2010 would increase BMI by 0.1. Table 53 shows that the remaining anthropometric indices are not associated with IMD 2010 ($p>0.05$)

Table 53. Impact of IMD 2010 on anthropometric indices

	Coefficient (95% CI)	P values
Weight	0.005 (-0.01, 0.02)	0.591
Height	-0.02 (-0.06, 0.01)	0.226
BMI	0.01 (0.002, 0.02)	0.016
Waist	0.01 (-0.01, 0.03)	0.300
Hip	0.006 (-0.02, 0.03)	0.657
W/H	0.0001 (-0.0002, 0.0004)	0.583
Triceps	0.02 (-0.002, 0.03)	0.443

6.4.10.2 Anthropometrics and Mosaic Supergroups

Using ANOVA models, it was shown that the mean BMI, weight, height, waist and hip circumference means did not differ between the different Mosaic Supergroup categories. However, there was a significant difference in children's triceps skinfold measurements based on the Mosaic Supergroups to which they belonged ($p=0.006$) (table 54).

Table 54. Associations between anthropometric measures and Mosaic Supergroups

Against Mosaic Supergroups	P values
Weight	0.641
Height	0.431
BMI	0.236
Waist circumference	0.759
Hip circumference	0.538
W/H	0.198
Triceps skinfold	0.006

Bonferroni multiple comparison tests showed that children who were in the Supergroup C ('Middle income families') and Supergroup D ('young people starting out') had a significantly lower triceps skinfold measurement as compared to those in Supergroup G ('social housing tenants') (table 55).

Table 55. Bonferroni multiple comparison results for triceps skinfold

	Supergroups		Mean difference	Significance (p value)
Triceps skinfold	C	G	-1.98064	0.034
	D		-2.22370	0.006

6.4.10.3 Dental caries and IMD 201 (Poisson)

The IMD 2010 was shown to be significantly associated with caries ($p<0.05$). More specifically, a 10 unit increase in a child's IMD 2010 would increase dmft rates by 1.3404 times.

6.4.10.4 Dental caries and Mosaic Supergroups (Poisson)

Using Supergroup G as a reference, children in Mosaic groups A-F were found to have significantly lower dmft scores (table 56).

Table 56. Associations between dental caries and Mosaic Supergroups

Mosaic Supergroup	Coefficient (95% CI)	P values
A	(-3.58, -0.61)	0.014
B	(-4.27, -1.30)	0.001
C	(-2.12, -0.99)	0.000
D	(-1.03, -0.25)	0.001
E	(-0.85, -0.13)	0.008
F	(-0.26, 0.32)	0.878

Further tests showed that children in Mosaic Supergroups B and C had lower dmft scores when compared to other groups, while children in Supergroups F and G had the highest dmft scores (all p -values<0.05).

6.4.10.5 Relationship between weight status and dental caries

Multiple logistic regression of both raw and z-scores of anthropometric variables, showed that neither of these variables was associated with the presence of caries (dmft>0). Table 57 shows the individual values (ORs, 95% CI and p-values) corresponding to each variable. The p-values were similar when either raw values or z-scores were used.

Table 57. Association between anthropometric measures and dental caries status

Anthropometric variables	OR (95% CI)	p-values
Weight	1.04 (0.96, 1.13)	0.301
Height	1.00 (0.96, 1.05)	0.881
BMI	1.14 (0.96, 1.34)	0.130
Waist	1.02 (0.95, 1.10)	0.602

Hip	1.03 (0.97, 1.09)	0.388
Triceps	1.04 (0.97, 1.13)	0.256

6.4.10.6 Further analyses on the study's questionnaire

Logistic regression showed that the parents/guardians of children residing in the most deprived areas (IMD-1), were less likely to respond and return the study's questionnaire, when compared to those in the least deprived areas of Plymouth (IMD-3) ($p=0.027$); the probability of response in parents living in areas of IMD-3, was 16% higher when compared to those living in IMD-1.

With regard to the variables included in the questionnaire, only the household's total income was found to be related to caries risk. More specifically, the higher the income, the lower the probability of having caries.

Our results also indicated that the reported frequency of tooth brushing was not affected by IMD category ($p>0.05$) or the household total income ($p>0.05$). However, the evidence suggested that parents' education level affected the frequency of tooth brushing. It was 71.6% more likely that children were reported to brush their teeth two times or more per day if their parents/guardians were University-level educated when compared to those who whose parents were secondary school-level educated.

6.4.11 Spatial results

Figures 16 and 17 show the mapping results for the rates of overweight/obesity and caries rates in our sample, where the rates refer to the number of affected cases per 100 children. The findings reveal a considerable geographical variation in the distribution of the two conditions in the sample.

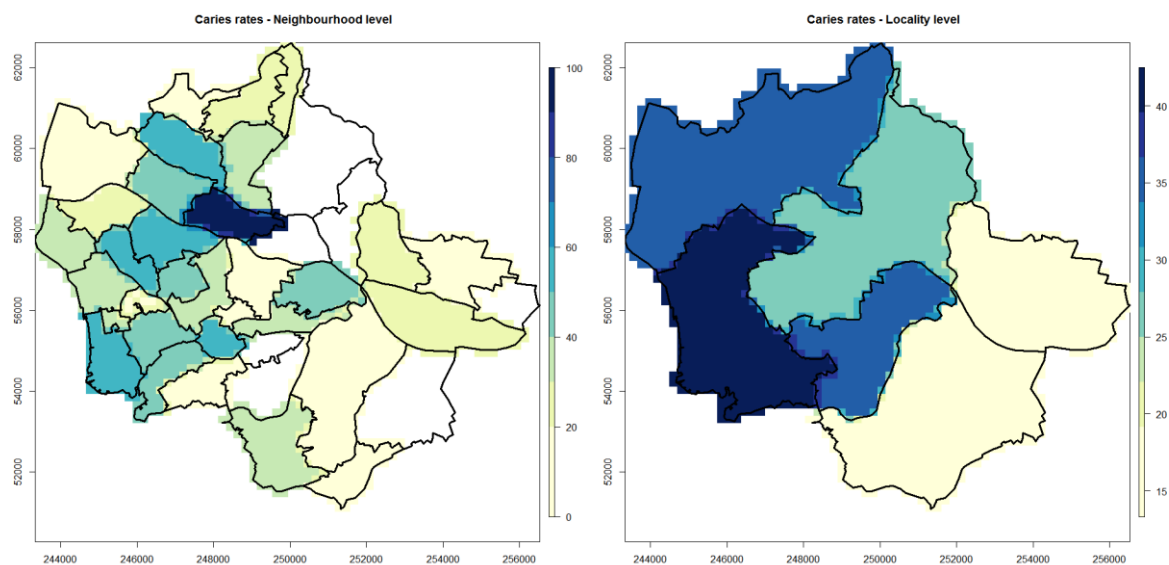


Figure 16. Caries rates by neighbourhood and locality in Plymouth sample

With regard to caries (at the locality level), higher rates were observed in the South West, followed by the localities of North West and South East (figure 20). The lowest rates were found in the southern east area of Plymouth, and more specifically in the localities of Plymstock and Plympton.

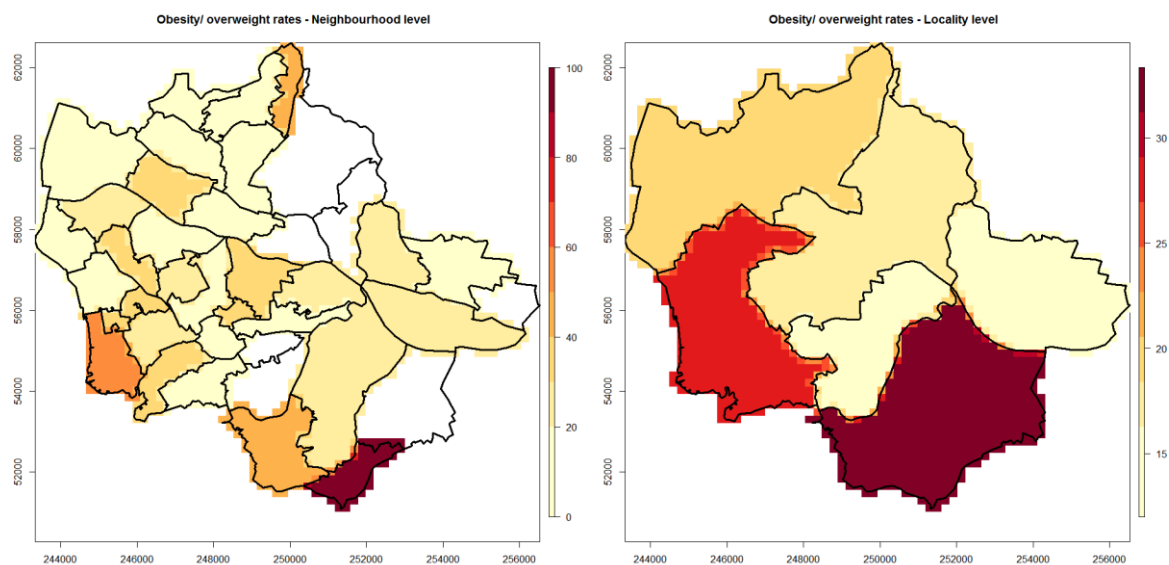


Figure 17. Overweight/obesity rates by neighbourhood and locality in the Plymouth sample

Overweight/obesity rates were found to be higher in Plymstock locality, and in the Southwest (figure 21). Lower values were observed in the northwest area of Plymouth, and specifically in the localities of South East and Plympton.

Based on the mapping results above, the highest rates of both overweight/obesity and caries were observed in South West, while in Plympton the lowest rates were recorded for both conditions.

6.4.11.1 Global Clustering

Results for the Moran's I test, together with the p-values are presented below (table 58).

Table 58. Spatial autocorrelation of overweight/obesity and dental caries in the Plymouth sample

	Moran's I statistic	p-value
Overweight/obesity	-0.41	0.09
Caries	0.19	0.03

The results showed a non-significant negative autocorrelation across localities in regards to obesity ($I=-0.41$, $p=0.09$), suggesting that the overall spatial pattern for the condition was random. In contrast, the spatial autocorrelation in caries was significantly positive, albeit small ($I=0.19$, $p=0.03$), indicating that there was some evidence against complete spatial randomness for caries.

6.4.11.2 Local clustering

Figure 18 displays the local clustering of the conditions using Moran's I statistic as the indicator.

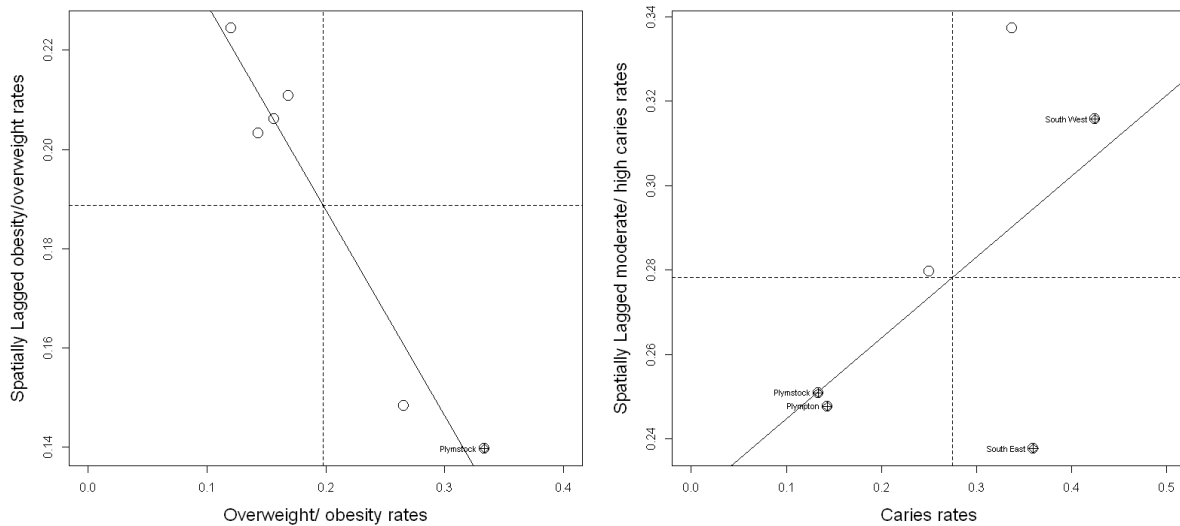
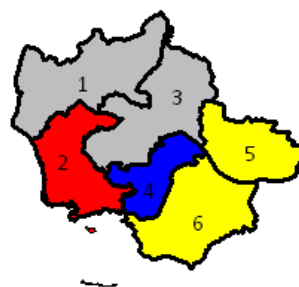
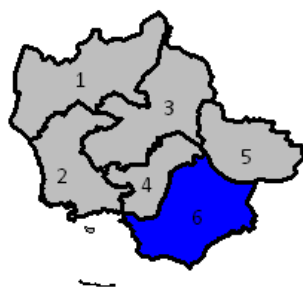


Figure 18. Local clustering of overweight/obesity rates and dental caries in the sample

The LISA cluster maps for obesity and caries at the locality level are displayed below.

Overweight/ obesity rates

Caries rates



- None
- High - Low
- Low- High
- High - High
- Low - Low

- None
- High - Low
- Low- High
- High - High
- Low - Low

1-North West locality
2-South West
3-Central and North East

4-South East
5-Plympton
6-Plymstock

Figure 19. Local clustering overweight/obesity and dental caries rates in the sample

The maps for overweight /obesity rates by locality suggest that Plymstock is a locality with significantly higher rates of the condition as compared to its adjacent localities (South East and Plympton).

Regarding dental caries, Plympton and Plymstock were identified as ‘cold spot’ areas (Low-Low areas), while South East is a high rate locality which is surrounded by localities of low values. Lastly, the South West locality was found to be a ‘hotspot’ for the condition.

6.4.11.3 Spatial dependence model (at neighbourhood level)

There appears to be a positive spatial relationship between caries rates and obesity/overweight rates at neighbourhood level. This was identified both by using a correlation test between caries and obesity/overweight rates at neighbourhood level ($p=0.79$, $p<0.001$) and by including obesity/overweight rates as a covariate in the spatial model for caries rates (which also corrects for the heterogeneous population distribution between neighbourhoods). In practical terms, one extra case of obesity/overweight in a neighbourhood, was associated with an increased caries rate in a neighbourhood of 1.06 times ($p=0.05$; marginal significance).

However, when covariates were included in the model, the positive association between caries and overweight/obesity was no longer significant.

6.4.12 Neighbourhood level determinants

In terms of covariates at neighbourhood level (i.e. lived in environment), despite a small effect size, it was shown that only the percentage of people on benefits affected both the obesity/overweight and caries rates. More specifically, at a 5% level of significance, the

percentage of people on benefits was found to be a significant predictor for caries rates (coefficient=0.04, $p=0.002$). In practical terms, a 1% increase in the percentage of people on benefits would increase the caries rate by 1.04 times.

Although at a 5% level of significance, no covariates were found to be significant predictors for overweight/obesity, at a 10% level of significance, the percentage of people on benefits was found to be a significant predictor for overweight/obesity (coefficient=0.03, $p=0.06$). This suggested that a 1% increase in the number of people of benefits would lead to a rise in overweight/obesity rate by 1.03 times.

6.4.13 Individual lifestyle behaviours

In terms of individual health behaviours, none of the reported covariates was associated with being overweight/obese. However, the presence or absence of dental decay appeared to be affected by the consumption of sugar confectionary, cakes and pastries, yoghurt desserts and fruits (fresh and dried). The detailed results are presented below.

Sugar confectionary: a significant difference was identified in the risk of the presence of dental decay between children who were reported to never consume sugar confectionary and children who were reported to consume sugar confectionary once a day ($p=0.03$); the odds of dental decay was 3.22 times higher for children who were reported to consume sugar confectionary once a day, compared to children who were reported to never consume confectionary.

Cakes and pastries: a significant difference was identified in the risk of the presence of dental decay between children who were reported to never consume cakes/pastries and children who were reported to consume cakes/pastries once a day ($p=0.004$); the odds of dental decay was 4.00 times higher for children who were reported to consume cakes/pastries once a day, compared to children who never did.

Yoghurt and other dairy desserts: a significant difference was shown in the risk of the presence of dental decay between children who reported to never consume yoghurt and other dairy desserts and children who were reported to consume these once or twice a day ($p=0.015$ and $p=0.004$ respectively); the odds of dental decay was 6.33 and 9.86 times higher for children who were reported to consume yoghurt and other dairy desserts once and twice a day respectively, compared to children who never did.

Fruit (fresh and dried): a significant difference was found in the risk of the presence of dental decay between children who were reported to never eat fruit and children who were reported to eat fruit once a day ($p=0.02$); the odds of having dental decay was 5.04 times higher for children who were reported to not eat fruit at all, compared to children who consumed fruit once a day.

6.5 Discussion

In the study reported in this chapter, area deprivation as determined by the IMD 2010, was found to be related to children's obesity status both at individual and area level. This is consistent with many epidemiological studies, including the NCMP which is conducted annually in England (Lifestyles Statistics Team: Health and Social Care Information Centre, 2015; Lifestyles Statistics Team: Health and Social Care Information Centre, 2013). However, the association identified in our study is not as strong as that shown in some studies.

The weak relationship between obesity and deprivation found in the present study is consistent with the findings of Conrad and Capewell (2012) who demonstrated that in younger children (aged 4-5 years) there was a weaker correlation between deprivation and obesity compared to that seen in children aged 10 to 11 years. Similarly, a cross-sectional study of data from 20,973 children in Plymouth aged between 5 and 14 years, showed that in girls, the relationship between obesity and deprivation became stronger

with increasing age (Kinra, Nelder & Lewendon, 2000). Thus, as mentioned in the previous chapter, taking into account the greater impact of deprivation on weight status among older children shown in other studies, it appears that the young age of the participants in our study (4-5 years) may explain our finding of a relatively weak relationship between deprivation and obesity. This could be due to the fact that deprivation-related factors may not have their full effect on children until they are older (Conrad & Capewell, 2012).

The mechanisms by which deprivation may be related to increased weight are not entirely understood. Evidence in the literature shows that dietary behaviours of disadvantaged children and therefore their vulnerability to weight gain are affected by household income and food price (Darmon et al., 2014; Kamphuis et al., 2006). Shortage of money may mean that parents purchase cheaper food for their children and such foods are commonly higher in fat and sugar than the more expensive are (Darmon & Drewnowski, 2008; Darmon et al., 2014; Epstein et al., 2007). However, in our study household income was not related to weight status, nor did the parents of obese children report higher frequency of consumption of sugar than their healthy weight counterparts. Thus, even though a link between sugar consumption and increased weight has been shown in several studies (Cantoral et al., 2016; Martin-Calvo et al., 2014; Mirmiran et al., 2015), our results did not show that the reported consumption of sugary items increased the risk of a child being overweight or obese. This is in agreement with the results of Peng et al. (2014a), who also found no significant association between obesity indices and reported snacking habits.

It is likely that the absence of an association between obesity and the frequency of sugar consumption in our study is due to the fact that we only had access to self-reported data and reported behaviour is often unreliable (van de Gaar et al., 2016). This is a common

problem in dietary surveys, particularly those which depend on memory recalls (Seidell, 1998). Given the strength of the evidence linking fat and sugar intake to obesity, the use of self-reported data probably, at least in part, explain why our results did not show a sugary food/obesity association. Research has also shown that parents frequently over-report the intake of foods/drinks perceived as healthy and to under report the intake of unhealthy items (Bornhorst et al., 2013). Thus, the parents in our study may have reported behaviours which they believed to be socially desirable, leading them to underreport their children's intake of items they considered to be unhealthy. Another possible explanation for the absence of an observed association between sugary items and overweight/obesity in the sample could be that the underreporting of intake is more of an issue among parents of children who are overweight/obese (Waling & Larsson, 2009). Lastly and very importantly, our study questionnaire focused only on the frequency of consumption of sugary items in-between meals. Obesity is known to be affected more by the amount of sugar rather than the frequency of sugar intake (Hayden et al., 2013) and this may well explain why there was no statistical association between consumption of sugary items measured by frequency and obesity.

Even though frequency of sugar consumption was not found by our study to affect the association between obesity and deprivation, there are other mechanisms that could affect the relationship. Based on evidence in the literature, this might be because children from lower SES in our study may have had other behaviours that have previously been linked to obesity, including low physical activity levels and/or an increased sedentary lifestyle. These behaviours were found to be more likely to be adopted by adolescents and young adults with a lower perceived social position within their community (Ritterman Weintraub et al., 2015). However, these potential explanations linking deprivation to obesity cannot be explored in the present study, as data on children's physical activity and sedentary lifestyle were not collected. It would

be useful for further research to explore the presence of these and other obesity related behaviours in obese children in combination with analysis of their dietary intake.

In contrast to obesity, the findings of the present study identified a strong association between deprivation and dental caries which is consistent with many other epidemiological studies. Several mechanisms could be responsible for the impact of deprivation on dental caries. Tickle et al. (1999), for example, reported that socioeconomic status and visiting behaviour had a significant effect on dmft of 5 year olds in the North West of England. In our study, however, the reported dental visiting behaviour of children in the year prior to the study was not related to children's dmft. This is not unexpected, as it is the child's day to day behaviour at home (diet, exposure to optimal fluoride) which has a much more profound effect on their oral health.

Our study showed that the household's total income was inversely related to children's dental caries experience and that parental educational level affected the frequency of children's tooth brushing, with children having better educated parents being more likely to brush their teeth twice a day or more. Both household total income and parental educational level were used as measures of a child's SES and it appears that they may at least partly explain the poorer dental caries outcomes in disadvantaged children in our study. The finding connecting parental educational attainment, particularly that of mothers' with children's tooth brushing habits is important, as parent's education has been linked to children's dental caries experience in other studies (Carta et al., 2014; Christensen, Twetman & Sundby, 2010; Chu, Ho & Lo, 2012; Peng et al., 2014b; Weatherwax et al., 2015). Furthermore, brushing frequency is crucial in caries prevention as tooth brushing is generally considered the most effective method of delivering fluoride and thus reducing the frequency of caries (Miller et al., 2012). Therefore, it appears evident that strategies to improve oral health habits in Plymouth

children should consider parents' educational levels, and preventive messages for this group may have to differ in some way to those targeted at other groups.

In relation to other possible mechanisms linking deprivation to dental caries, it has previously been shown that several characteristics and behaviours found among people of lower SES status may affect their oral health. These include, amongst others, fatalistic beliefs with regard to oral health, a lower perceived need for oral hygiene and lack of knowledge (Chen, 1995). Even though there is a possibility that some of these characteristics may have contributed to the higher burden of dental caries in children of lower SES in our sample, this hypothesis cannot be substantiated by the present study.

In contrast to the lack of any relationship between weight status and consumption of sugary items, our study showed that the presence of dental decay, irrespective of deprivation, was related to the reported frequency of consumption of sugar confectionary, cakes and pastries and yoghurt and other dairy desserts. This is in agreement with the findings of other studies (Al Ghanim et al., 1998; Burt et al., 1988; Chi et al., 2015; Hankin, Chung & Kau, 1973; Punitha et al., 2015). Although this assertion may appear to contradict our previous claim that there could be misreporting by the children's parents, it strengthens (but does not confirm) the argument that caries is affected by the frequency of sugar intake, whilst obesity is affected by the amount consumed. Taking into account robust evidence which points out sugars as the most important aetiological factor for caries (Moynihan et al., 2003; Rugg-Gunn, 1996; Sheiham & James, 2015), further enquiries exploring the pattern of snack consumption in Plymouth children should be developed. Evidence that frequency of sugar consumption is important would suggest that raising awareness on the best timing of snack consumption might be helpful.

The results of the present study indicate no relation between obesity and caries in Plymouth children (at the individual level), and this finding is consistent with other studies which used BMI as indicator of weight status (Alves et al., 2013; de Jong-Lenters et al., 2015; Granville-Garcia et al., 2008). Taking into consideration the results of the systematic review that was carried out as part of this PhD, it was hypothesised that BMI may not be the most suitable tool for assessing a child's weight status, especially when investigating the relationship of obesity and caries. This is because BMI cannot differentiate between fat mass and muscle or bone mass (Reilly, Boyle & Craig, 2009) and because, in contrast to the other types or indices of obesity, it does not indicate where the fat is located (Peng et al., 2014b). Thus, the conclusion was drawn that the association between obesity and caries may be affected by the type of obesity assessed. The mechanism which makes this biologically plausible is the evidence which shows that obesity in adolescence is related to decreased flow rate of saliva and caries and that the negative impact of obesity on the flow rate of saliva may be regulated by inflammatory mediators which are commonly associated with central obesity (Modeer et al., 2010).

In the current study however, no relationship between obesity and caries was identified, when waist circumference, W/H ratio or triceps skinfold were used as the metrics for overweight/obesity. Thus, the findings of our study do not support the hypothesis that the relationship of obesity with caries may depend on the type of obesity assessed. This is in disagreement with the results of Peng et al. (2014a), who found that in preschool children dental caries related to central obesity (as indicated by waist circumference). However, in agreement with our study, Peng et al. (2014a) found that obesity and dental caries did not relate when BMI was used as an indicator. Another study also showed that central and peripheral obesity, but not general obesity, related to dental caries experience in 12-year olds (Peng et al., 2014b). Thus, although in our study there was

no evidence to substantiate the hypothesis that caries in five year olds is related to either general or peripheral obesity or that the relationship can be affected by the type of obesity assessed, results of Peng et al.'s studies (2014b; 2014a) suggest otherwise. As studies in the literature examining the relation of central and peripheral obesity to caries are limited, no definite conclusions can be made as to whether they type of obesity assessed can influence the nature of the relationship between obesity and caries. Further research examining the relationship between different types/indices of obesity with caries, could help elaborate whether a relationship between the two conditions actually exists.

Earlier in this section, age was hypothesised as a possible reason for the relatively weak relationship that was found between obesity and deprivation in our study. Similarly, a possible explanation for the absence of an observed relationship between obesity (however measured) and caries in this study, despite the known common risk factors for both conditions, could be the age-dependent nature of the relationship (Hayden et al., 2013). It is possible that the relationship between obesity and caries does not manifest until later in life. This hypothesis finds support from several reports which have pointed out that the evidence of an association between the two conditions is more profound in the permanent teeth and is therefore more easily observed in older children (British Society of Paediatric Dentistry, 2015; Hayden et al., 2013). Therefore, it is reasonable to assume that the young age of our participants may be one of the reasons for the absence of an observed association between the two conditions. Hayden et al. (2013) suggested that the reason obesity and caries may become associated in older children could also be the increased sedentary lifestyle among older children and the unhealthy dietary habits associated with this type of behaviour (i.e. higher frequency of fatty and sugary snack consumption).

With regard to the impact of Mosaic Supergroups (which were used as a complementary measure of deprivation) on weight status and dental caries, our results indicated that children who were classified as Supergroup C ('middle income families') had better (lower) triceps skinfold measurements and lower caries when compared to children in Supergroup G ('social housing tenants'). Supergroup C is characterised by a comfortable way of living while Supergroup G is characterised by high unemployment, high dependency on welfare benefits and consists of the most disadvantaged populations in the UK (MAST, 2014a). Individuals belonging to the latter Supergroup G also have limited access to shops and their diets may be adversely affected as accessing fresh food is difficult (MAST, 2014a). Our results confirm that social inequalities in childhood obesity and dental caries in Plymouth remain evident when Mosaic Public Sector analysis is used instead of IMD. Mosaic Public Sector measures deprivation at a smaller scale than IMD does (household level vs LSOA) and can thus capture elements of deprivation that could be missed by IMD (Experian, 2006). Thus, it appears that the addition of Mosaic Sector in future studies could enable researchers to explore in more depth population characteristics and lifestyles that increase vulnerability to ill health.

In terms of the spatial distribution of the two conditions, our results showed significant geographical variability in overweight/obesity and dental caries rates. The results of global clustering revealed a systematic pattern in the overall spatial pattern of dental caries, therefore showing that values observed in one area relate to the values observed in a neighbouring area; this was not the case for overweight/obesity where the distribution appears to be random. Furthermore, as dental caries distribution appears to be non-random and since people living in neighbouring areas share similar lifestyles and behaviours, it would be interesting to examine whether certain behaviours which are believed to relate to the increase risk of caries are clustered in these areas.

The mapping results of our study indicated that the South West was the locality with the highest rates of caries, while Plympton and Plymstock were the localities with the lowest caries rates. A key difference between these localities is the percentage of people dependent on benefits and one parent families that live in these areas. A report from Plymouth City Council (Public Health: Office of the Director of Public Health: Plymouth City Council, 2014) indicates that the South West is the locality with the highest number of families that are 'low income, dependent on benefits and 'one parent families' (39.8% as compared to 23% of Plymouth average and 21.2% as compared 15.1% of Plymouth average, respectively) while Plympton and Plymstock have the lowest numbers of both 'families dependent on benefits' and 'one parent families'. Our spatial model showed that the percentage of people per neighbourhood dependent on benefits was associated with increased caries rates and to a lesser extent to the rates of overweight/obesity. Taken together, the proportion of 'people dependent on benefits' appears to explain, at least partly, the distribution of caries in Plymouth area, and could be used as an indicator for targeting caries in prevention programmes.

The spatial model also indicated a positive association between the two conditions at the area level, which seemed to be mediated by environmental living conditions. Because location affected the relationship between obesity and caries, further studies with bigger sample sizes are needed to examine the impact of several environmental variables on the relationship of the two conditions at the spatial level. These might include transport infrastructure, number of playgrounds, policies/programmes, availability of cycle/foot paths, traffic density, dietetic support centres and exposure to fluorides. All of these characteristics have been shown in other studies to affect the distribution of the conditions (Davison & Lawson, 2006; Do et al., 2014; Iheozor-Ejiofor et al., 2015)

either directly or indirectly by impacting on related behaviours (e.g. impact on physical activity).

A noticeable observation that came through the school survey's questionnaire analysis is that the parents/guardians who provided answers to the questions on their children's oral health and dietary habits, were almost invariably the mother rather than father. In their work, Ashkanani and Al-Sane (Ashkanani & Al-Sane, 2013) showed that mothers had better knowledge than other caregivers about the oral health habits of children aged less than six years of age. This hypothesis cannot be ascertained through our findings as comparative data on maternal and parental knowledge levels were not collected. However, as the family environment can influence children's eating habits significantly and because parents are the main regulators of children's eating and food supply particularly when children are very young (Ashkanani & Al-Sane, 2013; Campbell, Crawford & Hesketh, 2007), a better understanding of how family dynamics affect children's food choices would assist efforts aimed to bring about change in behaviour. The role of parents in shaping their children's oral health and dietary practices (Ashkanani & Al-Sane, 2013) perhaps needs to be better understood before developing intervention strategies targeting obesity and caries.

6.6 Limitations

The school study had limitations. Due to its cross-sectional design, this study was unable to infer any causal associations. However, the study gave insights into the impact of location on the two conditions and identified several individual and neighbourhood determinants of the rates and distribution of caries and obesity in Plymouth children.

As stated in an earlier chapter, the IMD 2010 does not necessarily accurately reflect the socioeconomic status of an individual. However, in addition to IMD which indicates area deprivation, the present study also used Mosaic Public Sector which estimates

deprivation at household level. Furthermore, the study also obtained information on children's individual SES.

A self-completed questionnaire was used to collect information on children's eating and oral health habits and their individual SES from the children's parents/guardians. Self-reported data have flaws, particularly in relation to habits, food intake and socially desirable characteristics.

Another limitation is that the questionnaire used to obtain the information described above was not validated. Validation of all methods is important to ensure that the tools/methods used accurately measure the outcome being evaluated. A more robust measurement of dietary intake using a validated method (i.e. 24 dietary recall conducted on several intervals in combination with a food diary, weighted inventory or food frequency questionnaire) would have provided more accurate picture of children's dietary habits.

However, such onerous methodologies would most likely reduce the response rate due to the burden placed on the parents. Despite the limitations of self-report, the data collected allow us to examine the impact of several confounders on the association between obesity and caries; many other studies in the field have omitted to include confounders in their analyses.

The anthropometric variables employed in this study are only an indirect measure of weight status and therefore have some disadvantages. These were discussed in depth in Chapter 2. Even though there are more accurate means for measuring body composition such as DEXA and computed tomography, their application is rarely possible because of their cost. In recognition of the weakness of BMI alone in defining excess weight, in the present study obesity was assessed not only at general, but also at peripheral and central level.

Another weakness of the current study was the fact that the sample size calculation was conducted with the aim of examining the study's main objective i.e. whether obesity and caries relate in Plymouth children. Therefore, the spatial analysis is weakened by the relatively small sample size.

6.7 Conclusions

The prevalence of overweight and obesity in Plymouth children aged four to six years involved in this study was lower than in the same age group of children in 2009. Although the comparison of these two results should be done with caution, due to different sampling method and considerably different sample sizes, the improvement is encouraging. However, with regard to dental caries, both the average number of affected carious teeth and the severity of decay in those who had some experience of decay, were found to be slightly higher when compared to the 2008/09 Plymouth figures.

The present study found no evidence of an association between obesity and caries in Plymouth children, regardless of the type of obesity that was measured. However, the area where children lived was found to affect not only the distribution, but also the relationship between the two conditions. Thus, even though there is no evidence of an association between the two conditions at the individual level, the study has shown that obesity and caries do indeed cluster in particular parts of the city.

Significant geographical heterogeneity was found in the distribution of the two conditions and spatial clusters of the two conditions were identified. These results reinforce the notion that geographic location is important and should be considered when developing future prevention and intervention strategies.

The finding that deprivation affects the prevalence of the two conditions was unsurprising and highlights the vulnerability of children living in deprived areas to excess weight and caries. It also highlights the importance of prioritising disadvantaged areas when developing intervention strategies targeting the two conditions in Plymouth.

Based on the evidence emerging from the study, important factors to be taken into account in future prevention and intervention strategies in the Plymouth include parental education (caries), area deprivation (obesity and caries) and geographic location (obesity and caries). This may suggest that the solutions to the development of chronic lifestyle related conditions may lie in the provision of education, employment and good housing in supportive environments, rather than the solutions being only the ‘correction’ of behaviours.

The novel method of spatial analysis presented here has been found to be useful in identifying areas of high risk of both obesity and caries in Plymouth children and the results suggest a connection between environmental characteristics and disease risk. Future longitudinal/prospective studies with larger sample sizes should explore the exact nature of the relationship between obesity and caries in different age groups and to examine in depth the impact of environmental characteristics relative to individual traits.

Chapter 7. General Discussion

7.1 Introduction

Childhood obesity and caries are issues of increasing public health concern. Even though they are both largely preventable, they represent two of the most common conditions affecting children nowadays. Their significant impact on children's physical and emotional health, in addition to the fact that they have lifelong effects, make it important that they are tackled at an early stage and ideally prevented from developing. However, before any intervention strategies or programs are developed, it is important to understand the conditions from a holistic perspective and to better comprehend how several factors operate on their own or synergistically to affect the two conditions.

This three part PhD investigated whether an association between the two childhood conditions exists and sought to explore and better understand the individual and environmental determinants which might affect the rates and distribution of the two conditions in Plymouth children. The analyses used in this PhD could serve as a model for prospective studies examining the association between the two conditions at regional or national level. It is also envisioned that the results of this PhD study will help to ensure that the University, in collaboration with other stakeholders, continues to contribute to the battle against health inequalities in Plymouth.

Below a summary of the results of all three parts of this PhD is presented, together with critical analyses and the implications the findings have for practice. Recommendations and conclusions based on the findings and current literature are also presented.

7.2 Main findings of the PhD work

7.2.1 Deprivation is a highly significant predictor for dental caries but not a strong one for obesity

The present PhD confirms the recognised fact that children from lower SES suffer a greater burden from both diseases (Health and Social Care Information Centre, 2015; Kinra, Nelder & Lewendon, 2000; Lifestyle Statistics Team: Health and Social Care Information Centre, 2014; Marshall et al., 2007; Santamaria et al., 2015; Sweeney, Nugent & Pitts, 1999; Weatherwax et al., 2015). However, the ecological study and school survey show that for the population under study, i.e. for children in Plymouth aged four to six years old, the association between deprivation and dental caries is stronger than between deprivation and obesity.

An extensive review of studies published between 1980 and 2010 examined inequalities in obesity prevalence among UK children (El-Sayed, Scarborough & Galea, 2012). The review found that deprivation both at area and at household level, as well as when individual measures were used, influenced obesity in children. In this PhD, the evidence was stronger for an association between obesity with area and household level deprivation; a direct association between individual-level measures of deprivation and obesity was not shown. A possible explanation for the absence of an observed association between individual SES and obesity in our study might be the measures of individual deprivation used. As El-Sayed, Scarborough and Galea (2012), indicated, not all household or individual-level elements of deprivation are associated with childhood obesity. Another possible explanation for this observation could be that changes in lifestyle across populations have made factors promoting obesity in the whole socioeconomic spectrum more common and have influenced affluent children to increasingly adopt habits known to promote increased weight (Conrad & Capewell,

2012). This would reduce inequalities, but it would increase the overall prevalence of the conditions. Further studies examining the impact of multiple indicators of deprivation on obesity risk will help expand knowledge on the complex synergy between deprivation and childhood obesity.

This PhD adds to the overwhelming evidence that deprivation is associated with dental caries and indicates that children from low SES should be considered as a high-risk population (Fontana, 2015). Although the mechanism by which low SES influences the development of caries in children has not been entirely elucidated either in the literature or by the present work, our findings show that the household's total income and parental educational level seem to influence children's dental caries experience and tooth brushing frequency, respectively. This is in agreement with the findings of Ashkanani and Al-Sane (2013), who indicated that the educational level of the parents strongly related to the oral health practices of their pre-school children. Both the literature and our study show that oral health behaviours are more caries promoting in children of lower SES. It is therefore clear that low SES children in Plymouth should be priorities for preventive care.

7.2.2 Mosaic Public Sector

Both the ecological and school survey indicated that households of the children who belonged to Mosaic groups that were associated with a high dependence on benefits and low incomes suffered from a greater burden of both caries and obesity. The Mosaic Public sector was used as a complementary measure of deprivation and it appears that its application in future studies might help explore further the complex interaction between deprivation, obesity and caries. It can also give useful insights into the lifestyles and characteristics of family units and can relate them to the structural environment.

7.2.3 Deprivation and response rates

Response rates for the parental questionnaire in our school study differed by deprivation level of household, with parents/guardians of children in more deprived areas being less likely to return the completed questionnaire. Witton and Nelder (2009) also showed that it was more difficult to obtain consent for dental examination from families in Plymouth living in more deprived areas. Taking into account that risk factors for chronic diseases are commonly clustered in individuals of lower socioeconomic status (Sheiham & Watt, 2000), it is essential that disadvantaged groups are adequately represented in future research. The present PhD has shown that deprivation is associated with both obesity and caries and that health inequalities currently persist in relation to both conditions. Our observations highlight the importance of researchers accessing difficult to reach populations. Identification of barriers to participation and exploration of facilitators that would encourage disadvantaged parents/populations to participate in research would enhance the validity of findings and would give better opportunities to relate results to the most at risk populations. To do this, researchers may have to accept longer timeframes, recognise higher resource needs and in particular establish partnerships with the communities in question (Bonevski et al., 2014).

7.2.4 Spatial elements in epidemiologic studies

In terms of the geographical distribution of childhood obesity and caries in Plymouth, the addition of the spatial analysis to both the ecological and school survey provided valuable information on the spatial dependence of the two conditions. It located clusters as well as hot- and cold-spots for the two conditions and provided evidence that location affects the distribution of the two conditions. The spatial heterogeneity identified means that geographical variation needs to be accounted for when developing strategies to target the conditions. The findings of the spatial model also indicate that the proportion

of the population in a locality in Plymouth who are ‘dependent on state welfare’ is a good indicator for assessing the vulnerability of a child to caries and obesity.

The presence of clustered health regions in our studies (ecological and school survey) indicate that living in these areas somehow represents a risk factor for both obesity and caries (Pouliou & Elliott, 2009). As it is known that areas in close geographical proximity share similar built and social characteristics (Campos et al., 2011), further exploration of our findings is warranted. For neighbourhood communities in Plymouth that have been shown to have similar rates of the two conditions, it may be that some behavioural determinants, as well as environmental influences on the conditions, also cluster (at the neighbourhood level) (Penney et al., 2014). When adjacent communities were not shown to have similar rates, the individual and environmental determinants of the two conditions may follow a different and more complex path (Penney et al., 2014). It is plausible that there are structural characteristics in these high risk areas that were not examined (e.g. opportunity for physical activity, easier access to healthy foods) which could affect the distribution of both obesity and caries in Plymouth children. It would therefore be interesting for future studies to examine further the potential mechanisms leading to the current patterns.

7.2.5 Relationship between obesity and caries

A major objective of this PhD work was to explore the association between obesity and caries. In the ecological study it was not possible to conduct an assessment of the relationship between the two conditions at the individual level due to the data being from different samples. However, the systematic review revealed that there was no consistent evidence of association between the two conditions when obesity was determined by BMI. Other systematic reviews have also shown that when BMI is used to define obesity, the association identified between obesity and caries is not consistent

(Hayden et al., 2013; Hooley et al., 2012; Kantovitz et al., 2006; Li et al., 2015a). The school survey along with many other studies in the literature (Costa, Daher & Queiroz, 2013; de Jong-Lenters et al., 2015; Edalat et al., 2014; Peng et al., 2014b; Peng et al., 2014a), also showed that obesity as measured by BMI was not associated with dental caries.

A possible explanation for these observations could be the fact that in some studies confounding variables were not considered in the analyses (Modeer et al., 2010). Our systematic review showed that the majority of studies failed to consider potential factors that are related to or affect both conditions (e.g. SES, diet, oral health habits). Furthermore, it could be that the duration that participants suffer from excess weight may affect the relationship between caries and obesity (Kantovitz et al., 2006; Modeer et al., 2010) and therefore longitudinal studies are better suited to examine the association between the two conditions. Conflicting results may also be due to factors including but not limited to: differences in participants' age, the measurement methodology, sensitivity of examinations, sampling methodology, study setting, population studied, underlying prevalence of the two conditions (Hayden et al., 2013; Hooley et al., 2012; Kantovitz et al., 2006; Li et al., 2015a; Silva et al., 2013).

It has been suggested that dental caries might be related to central obesity or obesity as indicated by skinfold thickness rather than general obesity (i.e. BMI). In a previous study of 12 year olds for example, only central and peripheral obesity related to the children's caries experience (Peng et al., 2014b). However, in another study of five years olds, dental caries related to general (when determined by weight/height ratio) and central, but not obesity as measured by triceps skinfold thickness (Peng et al., 2014a). These findings suggested that the measure used to define obesity may affect the association identified between obesity and caries. Yet, the results of our school study do

not support the hypothesis that the relationship is dependent on measure of obesity used. As studies examining the association of central obesity or obesity as indicated by skinfold thickness with caries are very limited in number, a definite conclusion cannot yet be drawn and the relationship between the two conditions appears to be complex. It could be that the two conditions may not be directly related, but that they simply coexist, as they share common aetiologic factors and that they strengthen each other's adverse impact (Bimstein & Katz, 2009). Further research should examine whether the relationships between caries and different types of obesity change over the life course. Again, longitudinal studies of the two conditions would be particularly informative.

7.2.6 What are the implications for practice?

The absence of a clear association between obesity and caries might be taken to indicate that each condition should be targeted in different preventive programmes. This was suggested after a recently conducted study in the Netherlands showed that having caries was not a predictor of being overweight or vice versa in children aged five to eight years old attending a dental referral practice (de Jong-Lenters et al., 2015). The authors stated that based on their results alone one could argue that dental intervention could not play a role in preventing obesity.

However, our work indicates that even though the two conditions may not be directly related they share common determinants. For example, despite the absence of an association between obesity and caries in Plymouth children, the present PhD work indicated that the two conditions are impacted upon by several common determinants such as area and household deprivation and that they cluster in some neighbourhoods and localities. The clustering of the conditions further suggests that there could be other common environmental determinants which affect individual behaviours that can impact on both conditions. Also, even though reported frequency of sugar consumption

was found to affect caries only, it could be that it is the amount, rather the frequency of sugar consumption that matters in relation to weight. Thus, sugar is most likely to negatively affect both conditions but in different ways.

Taking into account our findings and evidence in the literature showing that interventions targeting only individual behaviours and lifestyles are ineffective in improving health conditions (FDI 2015; Sheiham & Watts 2000), it appears that even if the two conditions are not directly related, targeting their common determinants and broader determinants of health which influence individual choices, would most likely be more successful way of reducing the prevalence and severity of the two conditions. Doing so through a multidisciplinary and combined approach may also possibly have a positive impact on other chronic conditions (Splieth, Christiansen & Foster Page, 2016).

The main principle in the common risk factor approach is that by targeting some risk factors, a beneficial effect on a number of diseases can be achieved with greater efficiency and effectiveness and at lower cost (Sheiham & Watt, 2000). Although the benefits of such an approach may not appear till later in life, the earlier that risk factors are targeted, the better the outcomes are likely to be. Such an approach would enable public policy makers to deliver consistent messages to the general public and would improve the efficiency, effectiveness and cost implication of interventions to reduce both conditions. Lastly, as this approach targets the broader determinants of health and aims to improve the health of the general population and those at increased risk, it is more likely that it will reduce the prevailing health inequalities (FDI World Dental Federation, 2015; Sheiham & Watts 2000; WHO, 2016a). The importance of targeting the external factors influencing the environment and living conditions (e.g. policies on education, sugar etc) should not be overlooked.

7.3 Recommendations at local and national level

7.3.1 Collaborative work

The present project was a collaborative work between Plymouth City Council, Public Health England (PHE) and the University of Plymouth. Each party's input was paramount to the development and implementation of the project. For example, Plymouth City Council has had years of experience of implementing the NCMP while PHE is the organisation responsible for the conduct of dental health surveys at the national level. The Plymouth City Council had great understanding of the barriers and facilitators to accessing the local schools and provided us with valuable information on the schools as well as geographical and other data that were needed for the analyses. The findings of this PhD work will be fed back to Plymouth City Council to inform decision-making.

An issue that was paramount to the successful implementation of the school survey is believed to be the initial approach to the schools and their engagement thereafter. The fact that a letter of support from the Local Authority was sent to the schools together with the study's invitation letter/information sheet, is believed to have substantially improved the schools' response rate.

- **Recommendation 1:** *A memorandum of agreement between stakeholders in the community who are involved with research, policy or other aspects of obesity and caries could enhance community efforts to reduce the burden of the two conditions.*
- **Recommendation 2:** *Collaborative working between Universities, City Council and Public Health England at the Local Authority Level should be supported.*

7.3.2 Relationships between academics and the schools

A good relationship between the University and the schools was important when communicating with the schools. These relationships had been built up over previous years through different community engagement projects conducted between the University and the schools concerned. Furthermore, while discussing possible involvement of the school (via a telephone conversation) it was evident that the lower the workload the survey would pose on the administrative staff and teachers, the more likely a positive response would be.

- **Recommendation 3:** *Fostering good relations between academics/research staff and schools in the community through different initiatives can improve access to potential research settings and could improve the generalisability of results by improving levels of involvement in research.*

7.3.3 Merging national surveys

Combination and coordination of national surveys would decrease the administrative efforts of the schools substantially and could potentially improve school participation rates in these and other surveys. This would consequently enhance the representativeness and generalisability of research results. Furthermore, it would allow expansion of the analyses and enable the investigation of the relationship between obesity and caries in one group of children at national level with a considerable sample size. Currently, although the NCMP and the dental health survey focus on five year olds (the NCMP includes all children at the reception year aged 4-6 years), these are carried out separately. Therefore a valuable opportunity to merge large datasets is being lost. In addition, the fact that the conduct of surveys sometimes coincide meaning that schools are more likely to refuse participation in one or either of them; this would most probably be the Dental survey as it is based on positive consent.

- **Recommendation 4:** *Combining the national surveys (on obesity and caries) would have the benefit not only of improving participation, but would also substantially improve the power of statistical analyses.*

7.3.4 Broader and common determinants of obesity and caries

Obesity and caries are most commonly analysed from a behavioural perspective, with many of the studies examining how demographic, dietary and oral health habits affect the prevalence and/or severity and relationship between the two conditions. However, several environmental and social factors could contribute to obesity and caries, as lifestyle behaviours are more often the result of the social and cultural environment rather than a simple trait of the individual (Multiple Risk Factor Intervention Trial Research Group, 1982). Our evidence strongly suggests that it is important to better comprehend the geographical determinants of both diseases. However, apart from our work, other studies examining the community determinants that may contribute to the emerging patterns of the two conditions have not yet been undertaken.

- **Recommendation 5:** *Further research using larger sample sizes, into potential structural and social determinants of obesity and caries and how they may interact to produce the emerging patterns is needed.*

It could be argued that establishing the direction of any association between obesity and caries is important as doing so would allow for the identification of the common causal behaviour pattern, which in turn could potentially allow identification of appropriate preventive interventions. However, even though the two conditions may not be directly related, they do appear to share similar determinants.

- **Recommendation 6:** *Further studies exploring the common determinants of obesity and caries could assist future efforts to address the two conditions.*

7.3.5 Spatial analysis

The recommendations above reiterate the importance of employing spatial statistics in the study of obesity and caries and expanding traditional epidemiological studies by adding spatial analyses. The spatial analysis results of this PhD work indicated consistently that geographic location affected the distribution of both conditions.

- **Recommendation 7:** *Employing spatial methodologies in the analyses of both conditions would provide the opportunity to better explore the impact of location on obesity and caries.*

7.3.6 Parental characteristics

An essential element to consider in needs-assessment studies and/or intervention programmes targeting obesity and caries is the parental/guardian characteristics and background. This is because family can greatly influence children's health behaviour and overall health. Also, parents can significantly affect children's attitude towards healthy behaviours, as well as their dietary and oral health habits at a very young age. Furthermore, because food availability at home is determined by the parents' decisions, understanding the precursors of the parents' decision making is important.

- **Recommendation 8:** *Prevention and/or intervention programmes targeting young children's health behaviour and oral health should focus on children's parents.*

7.4 Contribution to scientific knowledge

7.4.1 Systematic review

Systematic review

The systematic review provides updated information on the association of caries and obesity in youth using a validated and study-design specific tool for the appraisal of the

study quality. None of the previous reviews examining this relationship used critical appraisal tools that met the above criteria. The review also highlights several methodological issues that need to be addressed when conducting studies in the caries/obesity research field.

Contribution:

- Illumination of methodological pitfalls in obesity/caries research,
- Improved methodology for systematic review in the field.

7.4.2 Ecological study

As both datasets contained postcode-level data, the associations of interest in the ecological study were analysed not only at the individual but also at the neighbourhood level. Such a small area based approach enables better understanding of a population's health in the local context (Public Health Team: Plymouth City Council, 2014). Furthermore, analysis at the level of the 39 Plymouth neighbourhoods is particularly important as this is the geographic level at which interventions in the city can be implemented due to the configuration of local service providers.

By using a novel methodology to examine obesity and dental caries, the ecological study provides valuable information about spatial clusters of the two conditions in Plymouth. It also reinforces the notion of developing geographically focused strategies which take into account the presence of spatial heterogeneity. No other study has used this approach in examining the relation between obesity and caries. Furthermore, the application of spatial analysis has allowed the identification of areas with increased risk of childhood obesity and caries. Such information can inform public health professionals and policy makers working with childhood obesity and caries.

As well as analysing the existing datasets on a geographic basis, they were also analysed by Mosaic group. In this way, it was possible to investigate whether the relationships under investigation existed across specific Mosaic groups in the population or were restricted to specific geographic areas, a level of analysis which has not been used by any other studies in the field. Mosaic Public Sector has been shown to be a valuable complementary measure of deprivation. Dependency on benefits has proved to be an indicator of increased disease risk, particularly for caries.

Contribution:

- Introduction of novel methodology;
- Identification of high risk areas in Plymouth;
- Importance of Mosaic Public Sector analysis and benefit dependence identified.

7.4.3 School survey

The school survey not only examined the relationship between caries and general obesity, but also the relationship between caries and peripheral and central obesity. The latter relationships have not been previously examined in a UK population. Even though obesity (however measured) and caries did not relate at the individual level, the conditions were spatially related, thus reinforcing the need to explore further the impact of location on the patterns of the two conditions. As well as showing the impact of deprivation on obesity and caries, the study also showed how specific Mosaic Supergroups and specific elements of children's SES affected their vulnerability to increased weight and caries. The role of several characteristics of the environment in the emerging patterns was examined and it was shown that the number of people dependent on benefits is a good indicator of increased risk of ill health in a locality, particularly caries. The impact of neighbourhood characteristics has not been examined by any other

study examining the relationship between obesity and caries. Overall, a novel approach of examining the relation between the two conditions has been developed.

Contribution:

- First examination in the UK of different types of obesity in relation to caries;
- Identification of the importance of specific components of SES in increasing risk of caries;
- Identification of the importance of the effect of location and the lived-in environment on obesity and caries risk;
- Identification of novel methodology.

7.5 Limitations

With regard to the systematic review, the only index of obesity that was used to examine the relation between obesity and caries in the literature surveyed was the BMI. Examination of whether the use of other indices of obesity impacted the relationship could provide a clearer or different picture of any associations. However, studies examining the relation between different types of obesity and caries were rare up to the date that the current review was conducted.

Both the ecological study and school survey employed a cross-sectional design and as a result, they were limited in their power to make inferences about any causal relationship between caries and obesity. However, the present work did not aim to infer causality but rather to explore the nature of the association between the two conditions.

For the ecological study, in which we used secondary data analyses, the IMD was the main measure of deprivation used. This index assesses deprivation at LSOA level and therefore is prone to the ecological fallacy in that it may not reflect an individual child's

SES. However, the analysis was complemented with the Mosaic Public Sector which estimates deprivation at household level and can identify some aspects of deprivation which may be missed by IMD. In the school survey, we were also able to obtain information on individual children's socioeconomic status through the questionnaire by including questions on household total income and parental education in the study's questionnaire. The limitation was therefore to some extent mitigated.

Positive consent for both the dental survey of the ecological study and the school survey was required. As previously mentioned, this type of consent may result in underestimation of the disease level in the population as individuals from more disadvantaged backgrounds who often have the highest levels of disease are less likely to return the consent form. In addition, parents who knew that their children had issues with either their weight and/or dental health may have opted out from participation in fear that they would indirectly be the ones to be blamed for their child's overweight/obese status. However, obtaining a positive consent is a legal requirement in the UK and could not be ignored. Recognition of the potential biases introduced to the data by the use of positive consent is essential and is particularly important in the study of conditions known to be linked to deprivation.

Another limitation was the use of indirect indicators of obesity. Although BMI in particular, is a simple and the most recommended measure of weight status in children, the drawbacks associated with anthropometric methods (and analysed in detail in the literature review chapter) cannot be overlooked. However, it is almost impossible to employ more accurate methods of assessing body composition in epidemiological studies with large samples because of their cost and difficulties in transportation. The school survey was strengthened by the fact that different types of obesity were assessed

as the measurements were not limited to BMI but included waist and hip circumference and skinfold thickness; this approach has not been followed by many studies in the field.

7.6 Conclusions

Obesity (however measured) and dental caries in Plymouth children were not found to be associated at the individual level. The continuous inconsistencies in the literature and the evidence to date suggest that it is likely that no consistent relationship between the two conditions exists, especially in the primary dentition. This finding raises the issue of the possible need to change the current approach to how the relation of the two conditions is investigated. As the two conditions cluster spatially, a better approach for investigating whether the two conditions are related, appears to be focusing on exploring their common determinants (individual, social and environmental). This could be done through well-designed longitudinal studies using novel means of analysis, rather than simply sampling repeating cross-sectional studies with different populations.

- *Novel methods and new approaches to researching and addressing obesity and caries are required.*

Health inequalities in the distribution of both obesity and caries among Plymouth children still persist. Despite major efforts by governmental agencies and other independent organisations to tackle health inequalities, it appears that disadvantaged children in Plymouth still suffer a higher burden of obesity and caries. Taking into consideration the distribution of the two chronic conditions among children in Plymouth and the impact of area deprivation on the prevalence of both conditions, priorities should be given to interventions in areas with the highest deprivation levels.

- *Disadvantaged areas should be given priority when targeting obesity and caries in Plymouth.*

The present work illustrated a link between certain Mosaic public sector Supergroups and the distribution of both diseases. The addition of this indicator in future studies could provide additional valuable information.

- *Addition of Mosaic Public Sector analysis in public health analyses could add to knowledge regarding the elements of the broader environment that relate to obesity and caries.*

The results also suggest that the child's family characteristics and lifestyle, as indicated by this household indicator, should be accounted for when developing future prevention and intervention programs. Dependency on benefits is a valuable indicator of increased disease risk at the local level.

- *The impact on children's health of improvements to the lived-in environment should be examined in future studies.*

Identifying paths to reaching hard-to-reach populations both for research and in interventions is important. Collaboration between different stakeholders is valuable and can prove particularly beneficial in accessing such populations.

- *Multidisciplinary engagement is important in research, public health initiatives and health promotion.*

Important elements to take into account in the development of future programmes in Plymouth include, but are not limited to, parental education, area level deprivation and geographic location. Sugary items that were identified as being associated with higher caries levels in the present work should be prioritised in prevention and intervention strategies in Plymouth.

- *Characteristics of the lived-in environment and dietary items that have been shown to increase the risk of caries should be taken into consideration when developing programmes in the local context.*

Taking into consideration the parental influence in shaping children's health behaviours, it could be argued that, at least in the Plymouth context, where the mother's education was shown to influence children's tooth brushing habits, priority should be given to include the mothers when developing prevention programs and/or investigating children's habits.

- *Maternal educational achievement could be a key factor influencing Plymouth children's oral health habits.*

Spatial analyses methods, currently under-utilised in relation to the association between obesity and oral health, could offer great potential in informing future programmes and policies. As proven in the present PhD work, such methods can empower the traditional epidemiological methods for studying obesity and caries by locating clusters and identifying high risk areas. They can also relate individual and environmental factors to the observed patterns.

- *Novel research methodologies which examine chronic health problems from a fresh perspective are likely to improve insights into possible solutions.*

Appendices

Appendix 1. Key Policy documents in children's health -UK

Our priorities for 2013/14 (Public Health England, 2013)

Public Health England (PHE) which is a national agency aiming to promote the wellbeing of the nation, set five priorities for promoting health at the national level. Among these, was to give the youth the 'best start in life' by promoting healthy weight and targeting childhood obesity.

The relationship between dental caries and obesity in children (Public Health England, 2015)

In their report on the relationship between childhood obesity and caries, PHE reported that based on current evidence it is not possible to come to a definite conclusion about the association between the two conditions. However, they emphasised that as deprivation and high consumption of sugars are well known risk factors for both conditions, it is likely that interventions targeting these common features have the potential to impact both conditions at the national level (PHE 2015).

Obesity and Dental Decay in Children- A Position Statement (British Society of Paediatric Dentistry, 2015)

A recent position statement on obesity and caries in children by the British Society Paediatric Dentistry emphasised the need for a multiagency approach to tackling obesity and dental decay in the paediatric population. They also called on paediatric dentists to be vigilant when working within local teams so that overweight or obese children are identified in a sensitive and accurate manner and refer to local dietetic services for support.

Delivering better oral health: an evidence-based toolkit for prevention (Public Health England, 2014)

This is key document (third edition) for clinical teams which was developed after reviewing and revising evidence from previous editions and it enables them to provide patients with advice on improving and maintaining their oral and overall health, The aim of the document is to provide equal opportunity to all patients in terms of access to advice and care they can receive.

The Public Health Outcomes Framework for England, 2013-2016 (Department of Health, 2012)

In the Public Health Outcomes Framework for England which was released by the Department of Health, one of the indicators included was ‘tooth decay in children aged 5’. By including tooth decay as an indicator in this framework, it was anticipated that it would encourage the Local Authorities to prioritise oral health and initiatives to reduce tooth decay.

Unhealthy weight status in children aged 4 to 5 and 10 to 11 years was of the other indicators included in the framework, emphasising that obesity is a priority area of the UK government.

Monitoring of both indicators respectively, could be achieved through programs currently conducted at the national level, including the Dental Public Health Epidemiology Program of PHE, and the National Child Measurement Program.

The state of children’s oral health in England (RCS Faculty of Dental Surgery, 2015)

After taking into account the success of oral health programmes in Scotland and Wales, the Faculty of Dental Surgery at the Royal College of Surgeons of England

recommended among others that, the government should invest in national health programs to improve the oral health of English children. Furthermore, they suggested that efforts should be conducted to raise awareness on the negative impact of sugar on tooth decay and explore means to reduce consumption of sugar. They also urged the local Authorities who lack fluoridation schemes to introduce them in their areas in an effort to reduce inequalities in children's health.

Sugar reduction the evidence for action (Public Health England, 2015)

This reports highlights the fact that population consumption of sugar exceeds the current recommendations and reviews evidence from international interventions targeting sugar intake. It provides possible options of reducing sugar intake at the population level, emphasising that a multifaceted approach is needed to target the problem. This includes among others restricting marketing campaigns targeting children and revising policies on sugar content and portion sizes.

Childhood Obesity- A Plan for Action (HM Government, 2016)

This brief report summarises the UK's government plans to tackle obesity in children with the aim of significantly reducing the rate of the condition in children over the next ten years. It focuses primarily on reducing consumption of sugar and increasing physical activity. With regard to reduction in sugar consumption, the actions suggested include the introduction of soft drinks industry levy; reducing sugar in products by 20% focusing initially on nine food categories that contribute mostly to sugar intake of children; providing support to businesses to encourage them to make their products healthier; updating the nutrient profile model; continuing collaboration with the local authority and the Local Government Association to improve availability of healthy options in the public sector; supporting disadvantaged families with the cost of healthy food; assisting children in being active for an hour per day; improving the coordination

of quality sport and physical activity programmes for schools; introducing a new healthy rating scheme for primary schools in order to encourage them to help children eat more healthily and being more active; making food offered at school healthier; providing more clear information to families regarding food labelling; supporting settings related to food and physical activity at early childhood in the form of voluntary guidelines; using the power of technology to improve the food environment and eating choices; giving the ability to health professionals to provide support to families.

References:

British Society of Paediatric Dentistry (2015). *Obesity and Dental Decay in Children. A Position Statement*. Available at:

<http://bspd.co.uk/Portals/0/Public/Files/PositionStatements/Obesity%20and%20Dental%20Health%20Final%20PS%20Final.pdf>

Department of Health (2012). *The Public Health Outcomes Framework for England, 2013-2016*. London, Department of Health.

Public Health England (2014). *Delivering better oral health: an evidence –based toolkit for prevention*. London, Public Health England.

Public Health England (2013). *Our priorities for 2013/14*. London, Public Health England.

Public Health England (2015). *The relationship between dental caries and obesity in children*. London, Public Health England.

Public Health England (2015). *Sugar reduction the evidence for action*. London, Public Health England.

RCS Faculty of Dental Surgery (2015). *The state of children's oral health in England*. London, Royal College of Surgeons.

HM Government (2016). *Childhood Obesity- A Plan for Action*. London, Department of Health.

Appendix 2. Data Abstraction Form (continued)**Name of person extracting data:** _____**Date of data extraction:** ____ / ____ / ____**Study ID:** _____**I. General Information**

- **Author (s), year:** _____
- **Title:**

- **Publication type (e.g. journal article, abstract, letter):** _____
- **Journal 's name:** _____

II. Study Eligibility

Study characteristics	Eligibility criteria	Eligibility criteria met?		
		Yes	No	Unclear
Type of study	Observational studies including case-control, cross-sectional and cohort studies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Participants' age range	0-18 years	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Assessment of dental health	Objectively measured	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Anthropometric Assessments	Objectively measured	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Relationship between dental caries and anthropometric indices	Assessment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Data analysis	Primary	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Decision	INCLUDE <input type="checkbox"/> EXCLUDE <input type="checkbox"/>			
Reasons for exclusion (describe in detail)				
Notes				

DO NOT PROCEED IF STUDY EXCLUDED FROM REVIEW

III. Characteristics of included studies

➤ Methods

	Descriptions as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Aim & Objectives		
Study design		
Unit of allocation (e.g individual, hospital)		
Duration of participation(from recruitment to last follow up)		
Ethical approval obtained for study		

➤ Recruitment and Setting

	Description as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Country, city		
Setting (location)		
Inclusion criteria		
Exclusion criteria		
Sampling of the participants (e.g. randomised)		
Period of recruitment		
Period of data collection		
Informed consent obtained		

➤ **Data collection**

	Description as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Dependent variable (Anthropometry/disease): -Name -Measurement tool or method use -Outcome definition (with diagnostic criteria if relevant) -Person measuring/reporting		
Independent variable (exposure/risk factor)-Dental Health: -Name -Measurement tool or method use -Outcome definition (with diagnostic criteria if relevant) -Person measuring/reporting		
Confounding factors/effect modifiers measured: - Name for each and method of assessment		

➤ **Participants**

	Description as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Sample size calculation(how the study size was arrived at)		
Response rate		
Total number of participants		

Age		
Gender		
Race/Ethnicity		

➤ **Statistical methods**

	Description as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Describe all statistical methods, including any used to examine subgroups and interactions and those used to control for confounding		
Any sensitivity analyses		
How missing data are addressed		
Unit of assessment/analysis		
Sampling bias addressed in the analysis	<p>Not reported</p> <p><input type="checkbox"/> Weighing of the estimates by probability of selection</p> <p><input type="checkbox"/> Weighing of the estimates by nonresponse adjustment within sampling subgroups <input type="checkbox"/></p> <p>Post stratification by age <input type="checkbox"/></p> <p>Post stratification by sex <input type="checkbox"/></p> <p>Post stratification by race <input type="checkbox"/></p> <p>Not addressed in analysis <input type="checkbox"/></p> <p>Other (please specify) <input type="checkbox"/> -----</p> <p>-</p> <p>-----</p> <p>-----</p>	

➤ **Results**


	Description (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)																												
Participants	No of participants enrolled: No of participants included in the analysis: Number of withdrawals (& reasons): Number of exclusions (& reasons): Missing data:																													
Characteristics of study participants	<table border="0"> <thead> <tr> <th></th><th>Yes</th><th>No</th></tr> </thead> <tbody> <tr> <td>Socioeconomic If yes, please describe</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Demographic If yes, please describe</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Geographic If yes, please describe</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Other If yes, please describe</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> </tbody> </table>		Yes	No	Socioeconomic If yes, please describe	<input type="checkbox"/>	<input type="checkbox"/>	Demographic If yes, please describe	<input type="checkbox"/>	<input type="checkbox"/>	Geographic If yes, please describe	<input type="checkbox"/>	<input type="checkbox"/>	Other If yes, please describe	<input type="checkbox"/>	<input type="checkbox"/>														
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Confounding factors/effect modifiers accounted for in the analysis	<table border="0"> <thead> <tr> <th></th><th>Y</th><th>N</th><th>Un</th></tr> </thead> <tbody> <tr> <td>Diet</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>SES</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Oral Health Habits</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Age</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Ethnicity</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td></tr> <tr> <td>Other (please describe)</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/> _____</td></tr> </tbody> </table>		Y	N	Un	Diet	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	SES	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Oral Health Habits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Age	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Ethnicity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Other (please describe)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/> _____	
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Outcome data (Mean/median, SD or other variance, CC, OR, RR no. of participants, p value) a. Cohort study: report numbers of outcome events or summary measures b. Case-control study: Report numbers in each exposure category, or summary	Numbers- Summary measures Crude-Unadjusted estimates <i>Association between oral health and BMI:</i> Confounder-adjusted estimates <i>Association between oral health and BMI:</i>																													

measures of exposure		
c. Cross-sectional study: Report numbers of outcome events or summary measures		
Any other results reported (eg analyses of groups and interactions, and sensitivity analyses)		

➤ **Other information**

	Description as stated in report/paper (if data not available or unclear, please write not reported or unclear, respectively. If question not applicable to the study design, please write NA)	Location in text or source (pg&¶/fig/table)
Authors' reported limitations of study's methods/results		
Key conclusions of study authors		
Study funding source (including role of funders)		
Possible conflicts of interest (for study authors)		
Correspondence required for further study information (what and form whom and when)		
Correspondence received (from whom, what and when)		

Appendix 3. Appraisal tool for Systematic Reviews (*continued*)

 SIGN	Methodology Checklist 1: Systematic Reviews and Meta-analyses SIGN gratefully acknowledges the permission received from the authors of the AMSTAR tool to base this checklist on their work: <i>Shea BJ, Grimshaw JM, Wells GA, Boers M, Andersson N, Hamel C, et al. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. BMC Medical Research Methodology 2007, 7:10 doi:10.1186/1471-2288-7-10. Available from http://www.biomedcentral.com/1471-2288/7/10 [cited 10 Sep 2012]</i>	
Study identification (<i>Include author, title, year of publication, journal title, pages</i>)		
Guideline topic:		Key Question No:
Before completing this checklist, consider: Is the paper relevant to key question? Analyse using PICO (Patient or Population Intervention Comparison Outcome). IF NO reject. IF YES complete the checklist.		
Checklist completed by:		
SECTION 2: INTERNAL VALIDITY		
<i>In a well conducted systematic review:</i>		<i>Does this study do it?</i>
1.1	The research question is clearly defined and the inclusion/ exclusion criteria must be listed in the paper.	Yes <input type="checkbox"/> No <input type="checkbox"/> If no reject
1.2	A comprehensive literature search is carried out.	Yes <input type="checkbox"/> No <input type="checkbox"/> Not applicable <input type="checkbox"/> If no reject
1.3	At least two people should have selected studies.	Yes <input type="checkbox"/> No <input type="checkbox"/> Can't say <input type="checkbox"/>
1.4	At least two people should have extracted data.	Yes <input type="checkbox"/> No <input type="checkbox"/> Can't say <input type="checkbox"/>
1.5	The status of publication was not used as an inclusion criterion.	Yes <input type="checkbox"/> No <input type="checkbox"/>
1.6	The excluded studies are listed.	Yes <input type="checkbox"/> No <input type="checkbox"/>
1.7	The relevant characteristics of the included studies are provided.	Yes <input type="checkbox"/> No <input type="checkbox"/>

1.8	The scientific quality of the included studies was assessed and reported.	Yes <input type="checkbox"/>	No <input type="checkbox"/>
1.9	Was the scientific quality of the included studies used appropriately?	Yes <input type="checkbox"/>	No <input type="checkbox"/>
1.10	Appropriate methods are used to combine the individual study findings.	Yes <input type="checkbox"/> Can't say <input type="checkbox"/>	No <input type="checkbox"/> Not applicable <input type="checkbox"/>
1.11	The likelihood of publication bias was assessed appropriately.	Yes <input type="checkbox"/> Not applicable <input type="checkbox"/>	No <input type="checkbox"/>
1.12	Conflicts of interest are declared.	Yes <input type="checkbox"/>	No <input type="checkbox"/>
SECTION 2: OVERALL ASSESSMENT OF THE STUDY			
2.1	What is your overall assessment of the methodological quality of this review?	High quality (++) <input type="checkbox"/> Acceptable (+) <input type="checkbox"/> Low quality (-) <input type="checkbox"/> Unacceptable – reject 0 <input type="checkbox"/>	
2.2	Are the results of this study directly applicable to the patient group targeted by this guideline?	Yes <input type="checkbox"/>	No <input type="checkbox"/>
2.3	Notes:		

Appendix 4. Reasons for exclusion of full text articles (*continued*)

Authors	Reasons
Abolfotouh et al., 2000	No assessment of BMI
Acs et al., 1992	No assessment of BMI & caries relationship
Acs et al., 1999	No assessment of BMI & caries relationship
Al Ghalebi & El-Samarrai, 2012	Insufficient data provided
Alvarez, 1995	No assessment of BMI
Alvarez et al., 1993	No assessment of BMI
Alvarez et al., 1990	No assessment of BMI
Alvarez et al., 1988	No assessment of BMI
Alvarez et al., 1987	Insufficient data provided No assessment of BMI
Bagri et al., 2014	Insufficient data provided
Bastos et al., 2007	No assessment of BMI
Batista et al., 2009	Age range not meeting inclusion criterion
Bazroy et al., 2005	No assessment of BMI & caries relationship
Caballero & Kakehashi, 2003	No assessment of BMI
Campos et al., 2011	No direct comparison between BMI and dental caries
Chakravathy et al., 2013	Not appropriate classification of BMI
Chakravathy et al., 2012	Age range not meeting inclusion criterion
Chang et al., 2012	Full text not available
Chatterjee et al., 2012	Age range not meeting inclusion criterion
Chen et al., 2004	No assessment of BMI & caries relationship
Chu et al., 2013	No assessment of caries
Cinar et al., 2011	BMI not objectively measured
Cinar et al., 2008	BMI not objectively measured
Cleaton-Jones et al., 2000	No assessment of BMI
Conrey et al., 2009	No assessment of caries
Correa-Faria et al., 2013	No assessment of BMI
Ditmyer et al., 2011	BMI results not reported
Ditmyer et al., 2008	No assessment of BMI
Dye & Odjen, 2011	Review of another study-Commentary
Eronat & Eden, 1992	No clear assessment of BMI, no assessment of BMI & caries relationship
Floyd, 2009	Uses mean BMI for group
Geltman et al., 2001	No assessment of dental caries
Hooley et al., 2012	Dental caries not objectively assessed
Hu et al., 2004	Conference abstract
Ismail et al., 2009	No assessment of BMI
Ivanovic Marincovich, 1992	No assessment of BMI
Jinabhai et al., 1983	No assessment of BMI
Johansson et al., 1992	No assessment of BMI
Justo et al., 2014	No assessment of BMI
Kanchanakamol et al., 1996	No assessment of BMI & caries relationship
Kay et al., 2010	No assessment of BMI & caries relationship
Kramer et al., 2009	No assessment of dental caries
Lalla et al., 2006	No assessment of dental caries
Larsson et al., 1995	Uses mean BMI for group

Larsson et al., 1997	No assessment of BMI & caries relationship
Lawrence et al., 2004	No assessment of BMI & caries relationship
Li et al., 1996	No assessment of BMI
Liu et al., 2010	Conference abstract
Mohammadi et al., 2009	No direct assessment of BMI-caries relationship
Marshall et al., 2007	Insufficient data provided
Masumo et al., 2014	No assessment of BMI
Milaat & Grabrah, 1996	No assessment of BMI
Miller et al., 1986	No assessment of BMI
Miller et al., 1982	No BMI assessment and unclear how dental caries was assessed
Mishu et al., 2013	No assessment of BMI
Monse et al., 2013	No assessment of BMI & caries relationship
Moreira et al., 2006	No direct assessment of BMI
Nascimento et al., 2013	No assessment of BMI & caries relationship
Ou et al., 2012	Full text article not available in English
Padhy et al., 2013	Full text not available
Pasdar et al., 2014	Full text not available in English
Patil & Wasnik, 2009	No assessment of BMI & caries relationship
Peres et al., 2005	No assessment of BMI
Petti et al., 2000	Insufficient data provided
Poulton et al., 2002	Age not meeting inclusion criterion
Pourhashemi et al., 2007	No assessment of BMI
Prashanth et al., 2011	Insufficient data provided
Raducanu et al., 2011	No assessment of BMI
Reyers-Perez et al., 2013	Age range not meeting inclusion criterion
Scheiwe et al., 2010	No assessment of BMI & caries relationship
Shahabuddin et al., 2000	No details on caries assessment, no assessment of BMI & caries relationship
Shrivastava et al., 2005	Full text not available
Singh et al., 2012	Age range not meeting inclusion criterion
Sohn, 2009	Commentary on another study
Somani et al., 2013	Full text not available
Struska & Mielnik-Blaszczak, 2003	Full text not available
Tambelini et al., 2010	Age range not meeting inclusion criterion
Tavares et al., 2008	No assessment of BMI
Thomas & Primosch, 2002	No assessment of BMI
Tragler, 1981	No assessment of BMI
Tuomi, 1989	No assessment of BMI
Verma et al., 1989	Full text not available
Walket et al., 1988	No assessment of BMI
Yang et al., 2007	No assessment of BMI & caries relationship

Appendix 5. Table of Characteristics (*continued*)

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
6	Alkarimi et al., 2014	Saudi Arabia, Jeddah	Military primary schools	CS	417 Boys: 175 (42) Girls: 242 (58)	6 - 8 years	34-Very high	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) A cut off of <-2SDs was used to report underweight and stunting, whereas a cutoff of >+SDs was used to report obesity.	dmft	Negative An inverse linear relationship between caries status and children's BAZ was observed.
8	Alm et al., 2008	Sweden, Municipality of Jönköping	Schools & Public dental service clinics	CS of a longitudinal cohort	402 at age 15 years Boys: 206 (51.2) Girls: 196 (48.8)	15 years	12-Very high	BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values. (i) low normal weight (isoBMI < 25); (ii) overweight (isoBMI 25–29.9); and (iii) obesity (isoBMI ≥30).	D _{in} -initial caries D _{ma} -Manifest caries D _{i+m} Fa,-total approximal caries prevalence and fillings	Positive Overweight and obese adolescents had more approximal caries than normal-weight individuals
9	Alm et al., 2011	Sweden, Municipality of Jönköping	Child welfare centers, schools & Public dental service clinics	CS of a longitudinal cohort	525 at age 3 years 506 at age 6 years 402 at age 15 years Gender details not provided	1-15 years	12-Very high	BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values. (i) low normal weight (isoBMI < 25); (ii) overweight (isoBMI 25–29.9); and (iii) obesity (isoBMI ≥30).	At age 3 and 6 years: defs total and defs manifest At age 15 years: D _a D _{ma} D _{i+m} Fa.	Positive Overweight and obese adolescents had a statistically significant higher caries prevalence than normal-weight individuals.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
15	Alves et al., 2013	Southern Brazil, Porto Alegre	Schools	CS	1528 Boys:770 (50.4) Girls:758 (49.6)	12 years	79- High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Normal weight (BMI-for-age Z-score \leq +1 SD), Overweight (BMI-for-age Z-score $>$ +1 SD to \leq +2 SD), Obese (BMI-for-age Z-score $>$ +2 SD).	DMFT The presence of incipient caries lesions was also recorded.	No relationship No significant differences in caries experience or extent were observed among BMI groups.
16	Bagherian & Sadeghi 2013	Iran, Rafsanjan	Private and state-funded preschools	CS	400 Boys: 211 (52.8) Girls: 189 (47.2)	30-70 months	75- High	BMI-for-age Using standardized centiles derived from the first National Health and Nutrition Examination Study, 1971 to 1974 (Hammer et al., 1991). Underweight was defined as BMI-for-age $<$ 5 th percentile, Normal-weight 5th percentile $<$ BMI-for-age $<$ 85th percentile, At risk of overweight 85th percentile $<$ BMI-for-age $<$ 95th percentile, and Overweight BMI-for-age $>$ 95 th percentile.	defs	Positive There was an association between higher defs scores and severe early childhood caries with overweightness.
21	Bener et al., 2013	Qatar	Primary Health Care Centers (PHCs)	CS	1249 Boys:772 (61.8) Girls: 477 (38.2)	6–15 years	31- Very high	BMI for age- CDC Normal: $<$ 85 th percentile Overweight: 85-95 th percentile Obese: $>$ 95 th percentile	DMFT	Positive Being overweight or obese, was an independent risk factors for dental caries.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
22	Benzian et al., 2011	Philippines	Schools	CS	1951 Boys: 949 (48.6) Girls:1002 (51.4)	11-13 years	117-Medium	BMI-for-age- The children were grouped in 3 categories of BMI with age and sex related cut-off points according to the criteria of WHO (de Onis et al., 2007), CDC (Kuczmak et al., 2000), Philippines NHANS I (Department of Education, Health and Nutrition Center 1991) and Cole and colleagues (2007). For further analyses, the 3 BMI categories according to the Philippines NHANS I criteria were used.	DMFT/dmft and PUFA/pufa	Negative A significant negative association between caries and BMI was found.
24	Bhoomika et al., 2013	India, Mathura city	Department of Pedodontics and Preventive Dentistry (K D Dental College and Hospital)and schools	CC	200-100 caries free children (50 boys and 50 girls) and 100 children (50 boys and 50 girls) affected with S-ECC	3-6 years	135-Medium	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles 1) underweight (<5th percentile), 2) normal weight (fifth to 84th percentile), 3) at risk for overweight (>85th to 95th percentile) and 4) overweight (>95 th percentile)	defs	Positive A positive association between the BMI and S-ECC was observed.
27	Cantekin et al.,2012	Turkey, Erzurum	Department of Pediatric Dentistry, Faculty of Dentistry, Ataturk University.	CS	224 (boys)	12 years	69-High	BMI- The BMI was categorized into four Groups according to the International Obesity Task Force cut off values. low weight (BMI-1), normal weight (BMI-2), overweight (BMI-3), and obesity (BMI-4)	DMFT	Positive A positive relationship between obesity and dental caries (but not overweight) was found.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
33	Chen et al., 1998	Taiwan, Taipei city,	Original article in Chinese	CS	5133 Boys:2822 (55) Girls:2311 (45)	3 years	91-High	BMI-for-age Using standardized centiles derived from the first National Health and Nutrition Examination Study, 1971 to 1974 (Hammer et al., 1991). <5 th percentile: very low BMI 5 th - 25 th percentile: low BMI 25 th -75 th percentile: medium BMI 75 th -95 th percentile: high BMI >95 th percentile: obese	dft	No relationship There were no significant differences in the dft scores of carious children among different BMI groups.
35	Chukwuma h et al., 2012	Nigeria, Ugbowo, Benin City	Private and public schools	CS	210 Boys:110 (52.4) Girls:100 (47.6)	7-15 years	152-Low	BMI- the participants were categorized into underweight, normal, overweight, and obesity using the BMI percentile set thresholds for children of the same sex and age in CDC growth charts.	FT and DMFT	No relationship There was no significant association between BMI, DMFT and caries experience.
42	Costa et al., 2013	Midwest Brazil, East and North Health Districts of Goiania in the state of Goias	Households	CS	269 Gender distribution not provided	68.7 ± 3.8 months	79-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) . Children were categorized as severely thin (<-3SD), thin (<-2SD), normal weight (-2SD to +1SD), overweight (>+1SD, equivalent to BMI 25 kg/m2 at 19 years old), or obese (>+2SD, equivalent to BMI 30 kg/m2 at 19 years old)	dmft Significant Caries Index (SiC)	No relationship BMI was not associated with any of the three categories of dental caries.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
46	Dos Santos Junior et al., 2014	Brazil, Cabo de Santo Agostinho, southeastern part of Pernambuco	Municipal kindergartens	CS	320 Unclear if sample included children of both genders	3-4 years	79- High	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles 1) underweight (<5th percentile), 2) normal weight (fifth to 84th percentile), 3) at risk for overweight (>85th to 95th percentile) and 4) overweight (>95 th percentile)	ECC	Positive Positive significant relationship between obesity and prevalence of ECC was demonstrated.
48	Dye et al., 2004	USA	Mobile offices & households	CS	4236 Boys:2081 (50.8) Girls:2155 (49.2)	2-5 years	5 -Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Overweight: $\geq 95^{\text{th}}$ percentile At risk of being overweight: $\geq 85^{\text{th}} < 95^{\text{th}}$ percentile	dfs and ds	No relationship No association between caries and BMI was found.
50	Edalat et al., 2014	Iran, Shiraz	Kindergartens	CS	202 Boys: 101 (50) Girls: 101 (50)	3-6 years	75-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) and WHO Child Growth Standards (birth to age 5) The calculations for the two age groups were performed separately Each record with two standard deviations below the normal value (< -2), was esteemed as abnormal.	dmft	No relationship There was no significant relationship between increasing dental caries and BMI.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
51	Elangovan et al., 2012	India, Chennai city	Private, government-aided, and government schools.	CS	510 Boys: 266 (52.2) Girls: 244 (47.8)	6-12 years	135-Medium	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles 1) underweight (<5th percentile), 2) normal weight (fifth to 84th percentile), 3) at risk for overweight (>85th to 95th percentile) and 4) overweight (>95th percentile)	deft and DMFT	No relationship Dental caries scores showed no relationship with BMI-for-age in children.
54	Frazao et al., 2014	Brazil, Urban area of a small town within the western Brazilian Amazon	Schools & Households	CS survey nested in a population-based cohort study	203 Boys:95 (46.8) Girls: 108 (53.2)	7-9 years	79-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Children were classified in quintiles.	dmft/DMFT index	Negative Reduced caries experience was observed in children from the upper quintile of Z-scores for BMI.
55	Freitas et al., 2014	Brazil, State of Sao Paulo,	Public schools	CS	202 Group O - overweight/obese: 101 (45 boys & 45 girls) Group N - normal: 101 (45 boys & 45 girls)	12 years	79-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Overweight/obese: BMI \geq 85 th percentile Normal weight: BMI \geq 3 rd <85 th percentile	DMFT & SiC	No relationship Dental caries was not associated with obesity.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
57	Gerdin et al., 2008	Sweden, County of Ostergotland	Child welfare centres,school & public dental service clinics	CS of a longitudinal cohort	2303 Gender distribution not provided	4-12 years	12-Very high	BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values. Overweight (>25 kg/m ² at 18 years) and Obesity (>30 kg/m ² at 18 years)	deft (6 years) DFT (10 & 12 years), DFSa	Positive Overweight and caries prevalence were significantly associated.
58	Goodson et al., 2013	Kuwait	Primary schools	CS	8275 Boys: 3170 (38.3) Girls: 5105 (61.7)	11.36 ± 0.1 years	46-Very high	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Obese: Z-score > than 2 SD, Overweight: Z-score >1 SD, Normal healthy Weight: Z-score between1 and -2 SD. Underweight: Z-score <-2 SD	Number of teeth with fillings and visible unfilled decay	Negative Dental decay decreased with increasing obesity.
59	Granville-Garcia et al., 2008	Brazil, city of Recife	Public and private elementary schools	CS	2651 Unclear if sample included children of both genders	1-5 years	79-High	BMI z scores according to WHO criteria (1989) & National Centre for Health Statistics guidelines. Children with a Z score > 2 for the weight-height relationship were considered to be overweight.	DMFT	No relationship No relationship was found between dental caries and obesity.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
60	Heinrich-Weltzien et al., 2013	Philippines	Schools (public elementary)	CS	1962 Boys: 945 (48.2) Girls:1017 (51.8)	6-7 years	117-Medium	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Overweight: BMI-for-age > 1 SD Obese: BMI-for-age > 2 SDs Underweight: BMI-for-age < 2 SDs	dmft DMFT PUFA/pufa index (P/p), (U/u), (F/f) (A/a).	No relationship Children with a high dmft ratio were more likely underweight than children with a lower ratio. However the relationship was not significant.
61	Hong et al., 2008	USA	Mobile offices & households	CS	1507 Boys:48% Girls: 52%	2-6 years	5-Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Underweight – less than 5 th percentile; Normal weight – 5th percentile to less than 85th percentile; At risk of overweight – 85th to less than 95th percentile; Overweight – equal to or greater than the 95 th percentile.	dft	Overall, no relationship A statistically significant association between caries and obesity was found only for 60- <72-month age group and in the Hispanic and non-Hispanic Black strata.
62	Honne et al., 2012	India, Udupi District	Private and government schools	CS	463 Boys:252 (54.4) Girls: 211 (45.6)	13-15 years	135-Medium	BMI- according to the IOTF cut-off values Low- normal weight (BMI < 25), Overweight (25–29.9) and Obesity (BMI ≥30)	DMFT	Positive There was a significant positive relation with BMI, decayed teeth and DMFT.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
67	Jahani et al., 2013	Southeast Iran, Kerman	Primary schools	CS	906 Boys: 487 (53.8) Girls: 419 (46.2)	12 years	75-High	BMI- Standardized percentile curves of BMI in Iran Underweight: under the 5th percentile curve, Normal: between the 5th and 85th percentile, At risk of overweight: higher than the 85th and lower than the 95th percentile and Overweight as higher or equal to the 95th percentile.	dmft/DMFT	Negative Obesity was inversely related to dental caries frequency and severity.
68	Jamelli et al., 2010	Brazil, Municipality of Caruaru, State of Pernambuco	Public schools	CS and CC study nested within the cross-sectional study.	CS: 689 CC: 647 (465 cases to 182 controls). Boys: 271 (41.9) Girls: 376 (58.1)	12 years	79-High	BMI percentile –in accordance with the criteria adopted by the Dietary and Nutritional Surveillance System (SISVAN). This consisted of a percentile classification of BMI according to age and gender on the NCHS standard reference scale Underweight= < P5, Adequate weight = P5 to < P85, Risk of overweight = v P85 to < P95 and Overweight/obesity = v P95	DMFT	No relationship No significant relationship between caries prevalence and BMI was found.
71	Jurgensen & Petersen, 2009	Laos, Vientiane	Secondary Schools	CS	621 Boys: 293 (47.2) Girls: 328 (52.8)	12 years	139-Medium	BMI- IOTF cut off values and an empirical method which divided the children into tertiles.	dmft/DMFT	No relationship No associations were found between BMI and dental caries.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Cate gory	Definition of nutritional status	Measure of dental caries	Nature of relationship
75	Koskal et al., 2011	Turkey, Ankara	Primary schools	CS	245 Boys: 50.2% Girls: 49.8%	5-9 years	69-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19) Low weight, normal weight and overweight-obese, in accordance with the cut-off points of <-1SD, ≥-1SD — +1SD and ≥+1SD z-scores, respectively.	DMFT &DMFS	Negative BMI was negatively correlated with dmft indices.
76	Kopycka-Kedzierawski et al., 2008	USA	Mobile offices and households	CS	A total of 10 180 participants 2-5yrs: Boys: 2048/Girls: 2119 6-11yrs: Boys:1502/Girls: 1367 12-18yrs: Boys: 1304/Girls: 1473	2-18 years	5-Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Overweight: at or above the 95th percentile At risk for overweight: at or above the 85th percentile and less than 95th percentile Normal weight: less than 85th percentile	Dfs (2-11 years) and DMFS (6-18 years)	No relationship No statistically significant associations found between caries prevalence and weight status.
81	Lempert et al., 2014	Denmark, Odense	Schools	CS (prospective)	Baseline: 385 children Boys: 178 (46.2) Girls: 207 (53.8) Follow up: 280 children Boys: 127 (45.4) Girls: 153 (54.6)	8-10 & 14-16 years	10-Very high	BMI and BMI z scores- taking age-, sex- and growth- specific considerations into account National reference z-scores	dmfs/DMFS	Overall, no relationship Childhood caries was generally not associated with either BMI or subsequent changes in BMI. However, among children whose mothers were well educated, there was an inverse association between caries at baseline and subsequent changes in BMI.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
85	Macek & Milota 2006	USA	Mobile offices & households	CS	7617 (2-5 ys old; n=1,719) Permanent dentition (6-17 ys old; n=5,898) Gender distribution not provided	2 -17 years	5-Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: BMI-for-age less than the fifth percentile; Normal: BMI-for-age greater than or equal to the fifth percentile and less than the 85th percentile; At risk of overweight: BMI-for-age greater than or equal to the 85th percentile and less than the 95th percentile; and Overweight: BMI-for-age greater than the 95th percentile.	dft and DMFT	No relationship There was no significant association between BMI-for-age and dental caries prevalence in either dentition.
86	Mohammadi et al., 2012	Iran, Kerman	Primary schools	CS	407 Boys: 223 (54.8) Girls: 184 (45.2)	6 years	75-High	BMI - categorized based on WHO standards for children at the same age as follows: BMI < 13.25: underweight for age BMI 13.26-17.5: normal for age BMI 17.5-18.55: over weight for age BMI > 18.5: obese for age	dmft and DMFT	Positive There was a significant association between BMI and dental caries categories.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Cate gory	Definition of nutritional status	Measure of dental caries	Nature of relationship
88	Mapengo et al., 2010	Mozambique, Maputo	Government funded schools	CS	601 Boys: 241 (40.1) Girls:360 (59.9)	12 years	178-Low	BMI- 15th percentile was used as an indicator of malnutrition and the values above the 85th percentile were considered overweight indicators and obesity (95 th)	DMFT	No relationship The prevalence of caries was higher among young malnourished) when compared to overweight/ obesity but the differences were not statistically significant.
96	Mojarad & Maybodi, 2011	Western Iran, Hamedan	Private and state elementary schools	CS	1000 Boys: 500 (50) Girls: 500 (50)	6-11 years	75-High	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: under the 5th percentile curve, Normal: between 5th and 85th percentile, At risk for overweight : higher than 85th and lower than the 95th percentile Overweight: higher or equal to the 95 th percentile	DFT and dft	No relationship There was not a statistically significant relationship found between high weight and caries frequency in the first and permanent dentitions X (the association between underweight and high caries experience in total values dft/DFT in boys could be observed, although this relationship was not observed in girls).

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Cate gory	Definition of nutritional status	Measure of dental caries	Nature of relationship
100	Narksawat et al., 2009	Thailand	Primary schools	CS	862 Boys:411 (47.7) Girls: 451 (52.3)	12 - 14 years	89-High	BMI centiles- Other classification according to the Division of Nutrition, Thai Ministry of Public Health standard manual using weight for height in Thai children. Median with standard deviation (SD) was used as the cutoff point for nutritional status. Very thin: less than median minus 2 SD; Thin: median minus 2 SD to median minus 1.5 SD; Normal: median minus 1.5 SD to median plus 1.5 SD; Overweight: median plus 1.5 SD to plus 2 SD; and Obese: more than median plus 2 SD (Department of Nutrition, 2000).	DMFT	Negative An inverse relationship between nutritional status and the DMFT index was found.
104	Ngoenwiwatkul & Leelaadisorn, 2009	Thailand	Primary schools	CS	212 Boys: 117 (55.2) Girls: 95 (44.8)	6-7 years	89-High	BMI-for -age percentiles utilizing age and gender specific CDC (2007) BMI percentiles with some modification Underweight: BMI-for-age <5th percentile and “At risk” of being underweight: BMI-for-age from 5th to 15th percentile. In the analysis phase, no one had BMI-for-age < 5th percentile categories, thus the term “underweight” was used to refer to a group with <15th percentile of BMI-for-age.	dmfs & dmft	Negative Caries experience in primary dentition was an independent risk factor for being underweight.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Category	Definition of nutritional status	Measure of dental caries	Nature of relationship
105	Norberg et al., 2012	Southern Sweden. Skåne county	Child Health Care Centers	CS	920 Boys: 466 (50.7) Girls: (49.3)	5 years	12-Very high	<p>BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values and also statistical cutoffs for the groups normal weight, low weight, and underweight based on national epidemiological data on BMI in 5-year-olds in Sweden.</p> <p>Overweight: ISO BMI ≥ 25 Obesity: ISO BMI ≥ 30 This study used the international definition of overweight (ISO BMI ≥ 25) to define the combination of groups H (high weight) and O (obese), and the international definition of obesity (ISO BMI ≥ 30) to define group O. Group H was defined as ISO BMI ≥ 25 and < 30.</p>	deft and dt	Negative Overweight or obese children did not have higher deft or dt than others. However, children with low BMI had statistically significantly higher deft and dt than children with normal BMI.
106	Oliveira et al., 2008	Brazil, Diadema	Health centres	CS	1018 Boys: 519 (51) Girls: 499 (49)	12-59 months	79-High	<p>BMI-for-age z scores WHO Child Growth Standards 2006</p> <p>At risk underweight: z score < -2 Normal: $-2 \leq z \text{ score} \leq +2$ At risk overweight: z score $> +2$</p>	dmfs	Negative Underweight children were more likely to have caries experience.
112	Peng et al., 2014b	China, Hong Kong	Secondary schools	CS	514 Boys: 259 (50.4) Girls: 255 (49.6)	12 years	91-High	<p>BMI-for-age z scores WHO Reference 2007 (ages 5 to 19) and BMI Hong Kong Growth Survey weight-for-height criteria</p>	DMFT	No relationship Dental caries experience was associated with central and peripheral, but not general adiposity.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
113	Peng et al., 2014a	China, Hong Kong Island	Kindergartens	CS	324 Boys: 152 (46.9) Girls: 172 (53.1)	5 years	91-High	BMI-for-age z scores and BMI	dmft	No relationship Dental caries experience was not associated with general adiposity when BMI was used.
118	Powell et al., 2013	USA, Carolina	UNC Children's Hospital & Department of Pediatric Dentistry, UNC School of Dentistry	CS-Retrospective cohort	215 Boys: 119 (55) Girls: 96 (45)	3-5 years	5-Very high	BMI percentiles- P ₂₅ Median P ₇₅	dmft	Positive There was a statistically significant relation between dmft and overweight/obese.
120	Qadri et al., 2014	North-East Germany, District of Eastern Pomerania and Greifswald city	Primary schools	CS-prospective cohort study	694 Boys: 52% Girls: 48%	9-12 years	6-Very high	BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values. Low normal weight: isoBMI ≤ 25 Overweight: isoBMI >25–29.9 Obesity: isoBMI ≥ 30.	DMFT	Positive iso-BMI was associated with dental caries prevalence and severity at baseline.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
123	Sadeghi & Alizadeh, 2007	Iran, Isfahan	Private and state elementary schools	CS	633 Boys: 317 (50.1) Girls: 316 (49.9)	6-11 year old	75-High	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: <5thpercentile, Normal weight: fifth to 84th percentile At risk for overweight: >85th to 95th percentile and Overweight: >95 th percentile	DFT & dft	No relationship There was no association between BMI-for-age and DFT/dft indices.
124	Sadeghi et al., 2011	Iran, Rafsanjan,	State and private secondary schools	CS	747 Boys: 353 (47.3) Girls: 394 (52.7)	12-15 years	75-High	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Underweight – less than 5 th percentile; Normal weight – 5th percentile to less than 85th percentile; At risk of overweight – 85th to less than 95th percentile; Overweight – equal to or greater than the 95 th percentile.	DMFT	No relationship There was no association between DMFT scores and BMI-for-age scores.
125	Sakeenabi et al., 2012	India, Davangere city, Karnataka state	Schools	CS	1550 Boys: 798 (51.5) Girls: 752 (48.5)	6 and 13 years	135-Medium	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: less than 5 th percentile; Normal weight: 5th percentile to less than 85th percentile; At risk of overweight: 85th to less than 95th percentile; Overweight: equal to or greater than the 95 th percentile.	DMFT and dmft	Positive A significant association between caries frequency and obesity was identified.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Category	Definition of nutritional status	Measure of dental caries	Nature of relationship
129	Shahraki et al., 2013	Iran, Zahedan	Primary schools	CS	1213 Boys: 543 (44.8) Girls: 670 (55.2)	6-11 years	75-High	BMI-for-age Underweight: BMI-for-age < 5th percentile, Normal: 5th percentile < BMI-for-age < 85th percentile, At risk of overweight: 85th percentile < BMI-for-age < 95th percentile, and Obese: BMI-for-age > 95th percentile	DMFT & DFT	Positive There was a statistically significant association between BMI and DFT.
130	Shakya et al., 2013	India, Mangalore city	Not reported	CS	248 Gender distribution not provided	6,10 and 12 years old	135-Medium	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: less than 5 th percentile; Normal weight: 5th percentile to less than 85th percentile; At risk of overweight: 85th to less than 95th percentile; Overweight: equal to or greater than the 95 th percentile.	dft/DFT	Negative BMI score and dft score of deciduous dentition had a significant negative correlation.
131	Sharma & Hedge, 2009	India, Mangalore city	Department of Pedodontics and Preventive Children Dentistry, AB Shetty Memorial Institute of Dental Sciences	CS	500 Boys: 255 (51) Girls: 245 (49)	8-12 years	135-Medium	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles (2000) Underweight: <5 th percentile Normal: 5 th -85 th percentile Risk overweight:85 th -95 th Obese:>95 th	DMFS/dfs dmfs/DMFS	Positive Children with obesity and overweight had a significantly increased prevalence of dental caries in both primary and permanent dentition compared to normal weight children.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
132	Sheller et al., 2009	USA	Children's hospital	Retrospective-CS	293 Boys: 162 (55) Girls: 131 (45)	2-5 years	5-Very high	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: <5 th percentile Normal: ≥5 th and <85 th At risk of overweight: ≥85 th and <95 th Overweight: ≥95 th	dmft & the number of pulp-involved teeth (pulpotomies + pulpectomies + extractions).	No relationship BMI percentile did not correlate with dmft or the number of pulp-involved teeth.
138	Sood et al., 2014	India	Not reported-Elementary schools?	CS	280 Boys: 164 (58.6) Girls: 116 (41.4)	3-6 years	135-Medium	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Overweight: BMI-for-age at or above 95 percentile At risk of overweight: BMI for- age between 85th and 95th Underweight: BMI-for-age less than 5th percentile, and BMI-for-age between 5th and 85th percentiles under normal weight category. The BMI-for-age was plotted for each participant on the growth charts as standardized by CDC. Based on these growth charts, the sample population was distributed into three groups: Group I: Normal weight (5th-85th percentiles) Group II: Risk of overweight/obese (>85th percentile) Group III: Underweight (<5th percentile)	PI, dft	No relationship The differences between the mean dft values among the three BMI groups were not significant.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
140	Subramaniam & Singh, 2011	India, Bangalore City, Karnataka	Schools	CS	2033 children Boys: 1021 (50.2) Girls: 1012 (49.8)	6-15 years	135-Medium	BMI –for- age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: BMI-for-age < 5 th centile Normal: BMI-for-age ≥5 th <85 th centile Risk of overweight: BMI-for-age ≥85 th < 95 th centile Overweight: BMI-for-age >95 th	deft, DMFT	Negative & positive The mean deft score was significantly higher in underweight children. A significantly higher mean DMFT score was observed in children at risk of overweight and overweight children.
143	Thippeswamy et al., 2011	India, Udupi district	Private and government schools	CS	463 Boys: 252 (54.4) Girls: 211 (45.6)	13-15 years	135-Medium	BMI - using the international classification system for childhood obesity (isoBMI) recommended by the IOTF cut-off values. (i) low normal weight (isoBMI < 25); (ii) overweight (isoBMI 25–29.9); and (iii) obesity (isoBMI ≥30).	DMFT	Positive There was a significant association between overweight/obesity and caries experience.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
146	Tramini et al., 2009	France, Montpellier	Schools	CS	835 Gender distribution not provided	12 years	20-Very high	BMI-IOTF cut off values. For 12-year-olds these are as follows: BMI-1 = Insufficient (underweight), under 14.2 kg/m ² for girls and 14.3 for boys; BMI-2 = normal weight, between 14.2 and 22 kg/m ² for girls, between 14.3 and 21.4 kg/m ² for boys; BMI-3 = overweight, between 22.1 and 26.6 kg/m ² for girls, between 21.5 and 26 kg/m ² for boys; BMI-4 = obesity, over 26.6 kg/m ² for girls and over 26 kg/m ² for boys.	D ₃₊₄ MFT index DMFT	No relationship BMI was not statistically associated with DMFT.
147	Trikaliotis et al., 2011	Greece, Thessaloniki	Municipal day care centres	CS	361 children Boys: 183 (50.7) Girls: 178 (49.3)	3-5.5 year old	29-Very high	BMI-for-age-IOTF Underweight: <18.5kg/m ² at age 18, Overweight: >25kg/m ² at age 18 Obesity >30kg/m ² at age 18	dmfs	Positive Overweight children were found to show statistically significant differences in dmfs values compared with both children of normal weight and those who were underweight.
148	Tripathi et al., 2010	India, The city of Bareilly, Uttar Pradesh state	A private and two government schools	CS	2688 Gender distribution not provided	6-17 years	135-Medium	BMI-for-age and gender based on guidelines of National Centre for Health Statistics (1976) Underweight: < 90% of ideal for weight/height, Normal-weight: 90% to 110% of ideal for weight/height, Overweight: 110% to 120% of ideal weight for height, Obesity: >120% of ideal for weight/height.	DMFT	No relationship No correlation between dental decay in obese and non-obese children was detected.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Cate gory	Definition of nutritional status	Measure of dental caries	Nature of relationship
150	Van Gemert-Schriks et al., 2011	Interior of Surinam	Schools	CS	CS: 380 children CSBoys: 192 (48.6) Girls: 188 (51.4)	CS 6 years	100-High	BMI standard deviation cores (SDS) The SDS values were calculated according to Dutch references since there was no growth chart of rainforest children available.	Total-dmfs. Total-ds The presence of pulpal inflammation (pulp) was reported if a carious lesion had reached the pulp and/or when pulpal exposure was expected on excavation.	No relationship No significant correlations were found between BMI and dmfs cross-sectionally.
151	Vania et al., 2011	Italy, Rome	Paediatric Dentistry Department of Rome "Sapienza" University	CC	Total: 828 585 ECC (in abstract they say 586) & 243 Caries free ECC (n= 585): Boys: 318 (54.4) Girls: 267 (45.6) Caries free (n=243): Boys: 117 (48.1) Girls: 126 (51.9)	3-6 years	26-Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Underweight: <5 th percentile Normal weight: 5 th to 84 th percentile At risk for overweight: >85 th to <95 th percentile Overweight: > 95 th percentile	dmft and the number of teeth with pulp affected by caries.	No relationship The mean BMI percentile of the ECC group was not significantly different from that of the control group.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
152	Vazquez-Nava et al., 2010	Mexico, Area of Tampico-Madero-Altamira	Nursery schools	A CS study based on a cohort of 1,160 children	1,160 Boys: 582 (50.2) Girls: 578 (49.8)	4-5 years	71-High	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles Normal weight: 5-85th percentile At-risk overweight: $\geq 85^{\text{th}}$ and $< 95^{\text{th}}$ percentile; Overweight: $\geq 95^{\text{th}}$	df, dt	Positive There was a significant association between at-risk overweight children, overweight children and caries in the primary dentition
155	Werner et al., 2012	USA, North Carolina	Undergraduate pédiatrie dentistry elinie at the School of Dentistry	CS& retrospective review of a cohort	230 Boys: 116 (50.4) Girls: 114 (49.6)	6- 9 years	5-Very high	BMI-for -age percentiles utilizing age and gender specific CDC BMI percentiles (for 2-19 years).	DT, dt Plaque score	No relationship The presence of caries in permanent teeth at the initial exam was not significantly different between BMI groups The presence of new carious lesions at recall exams in primary and permanent teeth was not significantly different between BMI groups.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Cate gory	Definition of nutritional status	Measure of dental caries	Nature of relationship
156	Willerhausen et al., 2007	Germany	Dental hospital	CS	1290 Boys: 50.2% Girls: 49.8%	6-11 years	6-Very high	BMI- Calculation based on special tables from the obesity consortium for children and adolescents (Arbeitsgemeinschaft Adipositas in Kindes-und Jugendalter 2002)]. Low weight (BMI<20), Normal weight (BMI: 20-25), High weight (BMI: 25-30), Obesity (BMI>30)	DF-T and df-t	Positive A significant association between high weight and caries frequency in the first and in the permanent dentition was observed.
158	Willershausen et al., 2004	Germany, Mainz	Elementary schools	CS	842 Boys:428 (50.8) Girls: 414 (49.2)	6 -12 years (results) 6-11 (methods)	6-Very high	BMI- Calculation based on special tables from the obesity consortium for children and adolescents (Arbeitsgemeinschaft Adipositas in Kindes-und Jugendalter 2002)]. Low weight (BMI<20), Normal weight (BMI: 20-25), High weight (BMI: 25-30), Obesity (BMI>30)	DF-T- (df-t)	Positive There was an association between an increase of dental caries and high weight.
159	Willershausen et al., 2007	Germany, Mainz	Elementary schools	CS	2071 Boys: 998 (48.2) Girls: 1073 (51.8)	6-10 years	6-Very high	BMI-. Calculation based on special tables from the obesity consortium for children and adolescents (Flegal, 2005)	DF-T , df-t	Positive A significant association between the caries frequency and the BMI was found. A low BMI showed a correlation with the absence of carious lesions and a high BMI was linked to a high number of caries lesions (df-t + DF-T values.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
160	Wu et al., 2013	China, Tianjin	Stomatologic al Hospital of Tianjin Medical University	CS	280 Boys:151 (53.9) Girls: 129 (46.1)	7-12 years	91-High	BMI- according to BMI classification criteria for obesity of school children in China established by the Chinese Obesity Task Force [2004]-which take into consideration age and gender. The children were divided into two groups (overweight & normal weight)	DMF-T/S and dmf-t/s	No relationship No association was found between dental caries and obesity.
161	Xavier et al., 2013	Southern Brazil, In the city of Bauru, Midwest region of the state of Sao Paulo	Kindergartens (public)	CS	229 Gender distribution not provided	3-5 years	79-High	BMI-for-age z scores WHO Reference 2007 (ages 5 to19)	dmft	No relationship No significant correlation between the occurrence of dental caries and nutritional status.
162	Yevenes et al., 2012	Chile, Metropolitan Region of Santiago	Not reported-assume school	Descriptiv e, transversal, epidemiolo gical study,	571 Boys: 254 (44.5) Girls: 317 (55.5)	6 years	41-Very high	BMI-for age and gender comparing it to the CDC-NCHS reference, using the cut-points suggested by the Health Ministry Technical Norm.	DMFT	No relationship No association between caries and nutritional status in both deciduous and permanent dentition was shown.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
164	Yen & Hu, 2013	Taiwan, Taichung city	Day care centers	CS	329 Boys: 175 (53) Girls: 154 (47)	3-6 years	91-High	BMI- Based on BMI standards from the Department of Health in Taiwan: 'Lean-Underweight Normal weight Overweight and Obese.	deft	No relationship BMI was not significantly associated with dental caries
200	Cameron et al., 2006	Scotland, UK	Glasgow Dental Hospital	CS	165 52%girls 48%boys	3-11 years	Very high	BMI –UK 1990 growth reference adjusting for age and gender.	Dmft, DMF	Negative Severe dental decay was associated with underweight.
201	Chiu et al., 2013	US	Homeless shelter	CS	157 70-44.6% boys 87-55.4%girls	2-17 years	Very high	BMI - CDC 2000 Obesity was defined as a BMI > 95% on the CDC Children's BMI Tool for Schools.		No relationship Although BMI increased, as so did caries, the association was not significant.
202	Costacurta et al., 2011	Rome, Italy	Pediatric Dentistry Unit	CS	107 57 girls (53.3%) 50 boys (46.7%)	6-12 years	Very high	BMI- Italian population specific charts Underweight: BMI <3rd centile Normal weight: 3rd centile < BMI<95th centile Pre-obese: 75th centile<BMI<95th centile Obese: BMI>95th centile	DMFT, dmft	No relationship There was no significant association between pre-obesity /obesity as determined by BMI and increased dmft-DMFT.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
203	Creske et al., 2013	California, US	Elementary schools	CS	177 68 boys (38.4%) 109 females (61.6%)	3 rd grade students from elementary school	Very high	BMI – The BMI was calculated using the tool provided by the Center for Disease Control and Prevention	DMFT,	No relationship No significant association was found between an increase of the dmft-DMFT value and pre obesity/obesity.
204	De Moraes et al., 2010	Sao Paulo, Brazil	Public schools	CS	97 44 boys 53 girls	8to12	High	BMI percentile- American Academy of Pediatrics Obese: BMI \geq 95 th percentile for age; Overweight: BMI \geq 85 th percentile and < 95 th percentile; Normal weight: BMI \geq 5 th percentile and < the 85 th percentile; Underweight: BMI < 5 th percentile.	DMFT, Dmf	No relationship No significant difference in dental caries among children with different BMI was found.
205	D'Mello et al., 2011	Dunedin, New Zealand	Paediatric Dentistry Clinic	CS	196 106 (53.0) girls 94 (47.0) boys	8 years	Very high	BMI -Cole et al 2000 Children were categorised as normal, overweight or obese.	Dmft	No relationship There was no association between BMI and dental caries experience.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Category	Definition of nutritional status	Measure of dental caries	Nature of relationship
206	Fadel et al., 2014	Goteborg, Sweden	Obesity clinic	CC	55 29 boys 26 girls	16±2	Very high	BMI-Children were classified as obese based on the IOTF classification.	DFT, DFS,DS, FS	Positive Individuals with obesity had significantly more decayed tooth surfaces.
207	Gupta et al., 2014	Mathura, India	High schools	CS	100 50 boys 50 girls	12 years	Medium	BMI-CDC 2000 Underweight: BMI < 5th percentile. Healthy weight: BMI 5th percentile to < 85 th percentile. At risk of overweight: BMI 85 th to <95 th percentile. Overweight: BMI ≥95 th percentile.	DMFT/dmft	No relationship BMI had no significant effect on caries prevalence.
208	Güven Polat et al., 2012	Turkey	University pediatric dentistry clinic	CC	96 43 healthy (19 boys-24 girls) 53 obese (18 boys-35 girls)	Mean for obese: 10.4 Mean for healthy: 9.88	High	BMI-CDC Overweight: BMI 85-95 th percentile Obese: BMI >95 th percentile	DMFT, dmft	No relationship No association was found between obesity and dmft and DMFT scores.
209	Hilgers et al., 2006	Louisville Metropolitan area, US	Dental school	CS	178 85 boys 93 girls	8-11	Very high	BMI-international classification system recommended by IOTF. Categories used include normal weight, overweight and obese	Radiographs c-avg, C-avg	Positive Elevated BMI was associated with an increased incidence of permanent molar interproximal caries.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Category	Definition of nutritional status	Measure of dental caries	Nature of relationship
210	Loyola et al., 2010	Mexico	Oral medicine clinic and laboratory	CC	100 50 OB-IR 50 without OB-IR Unclear if sample included both genders	12-18	High	BMI- 2000 CDC growth charts for the US. Obesity: BMI \geq 95 th percentile Overweight: BMI \geq 85 th percentile and < 95 th percentile Normal weight: BMI <85 th percentile	DMFT	Positive Obese isulin resistant Mexican adolescents showed a positive association with DMFT.
211	Modeer et al., 2010	Stockholm, Sweden	University hospital- Division of Pediatric Dentistry	CC	130 65 obese 65 normal weight Gender distribution not provided	Obese mean age: 14.5 Healthy: 14.2	Very high	BMI IOTF classification and BMI adjusted for age and sex (BMI-sds) Obese: ISO-BMI >30 Normal weight: ISO-BMI <25	DMFT/S	Positive Obesity was associated with dental caries.
212	Pinto et al., 2007	Pennsylvania, US	Dental school	CS	142 67 girls 68 males	Mean 8.7	Very high	BMI –no categories provided, only reference to two previous surveys.	DS/ds	No relationship No correlation between dental decay in obese and non-obese children was found No significant association
213	Reifsnider et al., 2004	US	WIC Clinics	CS	104 59 boys 45 girls	1-20years	Very high	BMI- classification system not specified	ECC	Positive Children with a greater degree of caries experience tended to have higher BMI.

ID	Author, year	Country, City	Setting	Study design	Sample size and gender distribution (n, %)	Age group (years)	HDI/Catogory	Definition of nutritional status	Measure of dental caries	Nature of relationship
214	Sancez et al., 2010	Mexico city	Public elementary school	Longitudinal	110 (88 follow up) Unclear if both genders	7-11 follow up	High	BMI -CDC 2000 Overweight: BMI> 95 th percentile Risk of overweight: BMI≥ 85 th percentile and <95 th percentile Normal: BMI≥ 50 th percentile and <85 th percentile Thin: <50 th percentile and >5 th percentile Underweight: <5 th percentile	DMFT, DMFS	Negative A lower dmfs index was found in overweight children, as compared with children with a lower BMI.
215	Scheutz et al., 2007	Dar es Salam, Tanzania	Primary schools	Prospective cohort	218 147 122 Gender distribution not provided	Mean age baseline 7.6 years Mean age completion: 13.3	Low	BMI z-scores (Cole et al., 1998) Malnourished: BMI z-score≤ -1.96	DMFS	No relationship Malnutrition at baseline was insignificantly predictive for the development of caries
216	Tang et al., 2013	Kaoshiung, Taiwan	Department of Pediatric Dentistry	CS	101 38 girls 63 boys	2-5 years	High	BMI-CDC, Department of Health, Taiwan Children were classified as obese, overweight, normal or underweight	SECC	No relationship No significant differences were observed between defs scores and BMI categories.
217	Tong et al., 2014	Leeds, UK	Obese: Pediatric obesity clinic Community weight managemt group Normal weight:Orthopaedic Outpatient Fracture Clinic	CC	64 32 obese 32 normal weight	7-15	Very high	BMI-UK 1990 Growth growth charts (Cole 1990) Obesity: BMI> 98 th percentile	WHO scoring caries index, DMFT	No relationship No significant differences in the DMFT between obese and normal weight children were found.

Appendix 6. Risk of flaws in each individual study and across studies (L=Low risk, H= High risk, U= Unclear risk, NA= not applicable) (*continued*)

Risk of bias domains	Alkarimi et al., 2014	Alm et al., 2008	Alm et al., 2011	Alves et al., 2013	Bagherian & Sadeghi 2013	Bener et al., 2013
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	H	H	L	L	L
Assessment of outcome	L	L	L	L	L	L
Reliability of exposure estimates	U	U	U	U	L	U
Reliability of outcome estimates	L	U	U	U	L	U
Confounder assessment	H	H	H	H	H	H
Sampling bias	H	L	L	L	L	H
Research specific bias	L	L	L	L	L	U
Exclusion bias	U	L	U	L	L	H
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	U	U	H	U	U
Conflict of interest	L	U	U	U	U	L
Blinding	U	U	U	U	U	U
Selective reporting of results	L	L	L	L	H	L

Risk of bias domains	Benzian et al., 2011	Bhoomika et al., 2013	Cantekin et al.,2012	Chen et al., 1998	Chukwumah et al., 2012	Costa et al., 2013
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	L	L	H	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	L	U	U	U	L	L
Confounder assessment	H	H	H	H	H	H
Sampling bias	L	H	H	H	H	L
Research specific bias	L	H	H	H	H	L
Exclusion bias	L	L	U	U	U	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	L	U	U	U	U	U
Conflict of interest	L	U	U	U	L	L
Blinding	U	U	L	U	U	U
Selective reporting of results	H	H	H	H	H	H

Risk of bias domains	Dos Santos Junior et al., 2014	Dye et al., 2004	Edalat et al., 2014	Elangovan et al., 2012	Frazao et al., 2014	Freitas et al., 2014
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	L	H	L	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	L	L	U	U	H	L
Confounder assessment	H	U	H	H	H	H
Sampling bias	H	L	H	L	H	H
Research specific bias	L	L	H	L	L	H
Exclusion bias	L	U	L	L	L	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	L	U	U	L	U	U
Conflict of interest	L	U	L	L	L	L
Blinding	U	U	U	U	U	U
Selective reporting of results	L	H	H	L	L	H

Risk of bias domains	Gerdin et al., 2008	Goodson et al., 2013	Granville-Garcia et al., 2008	Heinrich-Weltzien et al., 2013	Hong et al., 2008	Honne et al., 2012
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	H	L	L	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	U	U	L	L	U	L
Confounder assessment	H	H	H	H	L	U
Sampling bias	L	H	L	L	L	L
Research specific bias	L	U	U	L	L	L
Exclusion bias	U	L	U	U	U	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	L	U	L	U	U
Conflict of interest	U	L	U	L	U	U
Blinding	U	U	U	U	U	U
Selective reporting of results	L	H	L	L	L	H

Risk of bias domains	Jahani et al., 2013	Jamelli et al., 2010	Jurgensen & Petersen, 2009	Koskal et al., 2011	Kopycka-Kedzierawski et al., 2008	Lempert et al., 2014
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	H	L	L	L	H
Reliability of exposure estimates	U	H	U	U	U	U
Reliability of outcome estimates	L	L	L	U	U	U
Confounder assessment	H	H	L	H	H	U
Sampling bias	L	L	L	H	L	H
Research specific bias	L	L	L	H	L	L
Exclusion bias	U	U	L	U	L	L
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	U	U	U	H	U
Conflict of interest	L	U	L	U	U	U
Blinding	U	L	U	U	U	U
Selective reporting of results	L	U	L	H	L	L

Risk of bias domains	Macek & Milota 2006	Mohammadi et al., 2012	Mapengo et al., 2010	Mojarad & Maybodi, 2011	Narksawat et al., 2009
Exposure definition	L	L	L	L	L
Assessment of exposure	L	L	L	L	L
Assessment of outcome	L	L	L	L	L
Reliability of exposure estimates	U	U	U	U	U
Reliability of outcome estimates	U	L	L	U	U
Confounder assessment	H	H	H	H	H
Sampling bias	L	H	L	H	H
Research specific bias	L	H	L	H	H
Exclusion bias	U	L	U	U	U
Attrition bias	NA	NA	NA	NA	NA
Funding	U	U	U	U	U
Conflict of interest	U	L	U	U	U
Blinding	U	U	U	U	U
Selective reporting of results	L	H	H	H	L

Risk of bias domains	Ngoenwiwatkul & Leela-adisorn, 2009	Norberg et al., 2012	Oliveira et al., 2008	Peng et al., 2014b	Peng et al., 2014a	Powell et al., 2013
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	H	L	L	L	L
Assessment of outcome	L	U	L	L	L	L
Reliability of exposure estimates	U	U	U	L	L	U
Reliability of outcome estimates	U	U	U	L	L	U
Confounder assessment	H	H	H	U	U	H
Sampling bias	H	L	H	H	L	H
Research specific bias	H	L	L	L	L	H
Exclusion bias	L	L	L	L	L	L
Attrition bias	NA	NA	NA	NA	NA	U
Funding	U	U	U	U	U	U
Conflict of interest	U	U	U	L	L	U
Blinding	U	U	U	U	U	U
Selective reporting of results	L	L	L	L	L	L

Risk of bias domains	Qadri et al., 2014	Sadeghi & Alizadeh, 2007	Sadeghi et al., 2011	Sakeenabi et al., 2012	Shahraki et al., 2013	Shakya et al., 2013
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	L	L	L	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	L	U	U	L	H	U
Confounder assessment	H	H	H	U	H	H
Sampling bias	H	H	H	L	H	H
Research specific bias	L	H	H	L	U	H
Exclusion bias	L	U	U	U	L	U
Attrition bias	L	NA	NA	NA	NA	NA
Funding	U	U	U	U	U	L
Conflict of interest	L	U	L	U	U	L
Blinding	U	U	U	L	U	U
Selective reporting of results	L	H	H	L	H	H

Risk of bias domains	Sharma & Hedge, 2009	Sheller et al., 2009	Sood et al., 2014	Subramaniam & Singh, 2011	Thippeswamy et al., 2011	Tramini et al., 2009
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	H	L	L	L	L
Assessment of outcome	L	L	L	L	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	H	L	U	L	L	U
Confounder assessment	H	H	H	U	U	U
Sampling bias	H	H	H	H	H	L
Research specific bias	H	H	H	H	L	L
Exclusion bias	U	U	U	U	L	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	U	L	U	U	U
Conflict of interest	U	U	L	U	U	U
Blinding	U	U	U	U	U	U
Selective reporting of results	H	L	H	H	L	L

Risk of bias domains	Trikaliotis et al., 2011	Tripathi et al., 2010	Van Gemert-Schriks et al., 2011	Vania et al., 2011	Vazquez-Nava et al., 2010	Werner et al., 2012
Exposure definition	L	L	H	L	L	L
Assessment of exposure	L	L	L	H	L	H
Assessment of outcome	L	L	L	L	L	H
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	L	L	L	U	L	U
Confounder assessment	H	H	H	H	H	H
Sampling bias	H	H	H	H	H	H
Research specific bias	H	H	H	H	H	H
Exclusion bias	U	U	U	U	U	L
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	H	L	U	U	U	U
Conflict of interest	U	L	L	U	U	U
Blinding	U	L	U	U	U	U
Selective reporting of results	H	H	H	H	L	H

Risk of bias domains	Willerhausen et al., 2007	Willershausen et al., 2004	Willershausen et al., 2007	Wu et al., 2013	Xavier et al., 2013	Yevenes et al., 2012
Exposure definition	L	L	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	L	H	L	L	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	U	U	U	H	L	L
Confounder assessment	H	H	H	H	H	H
Sampling bias	H	H	H	H	L	L
Research specific bias	H	H	H	L	L	L
Exclusion bias	L	U	U	U	U	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	U	U	U	U	U
Conflict of interest	U	U	U	L	L	L
Blinding	U	U	U	U	U	U
Selective reporting of results	L	H	H	L	H	H

Risk of bias domains	Yen & Hu, 2013	Cameron et al., 2006	Chiu et al., 2013	Costacurta et al., 2011	Creske et al., 2013	De Morais et al., 2010
Exposure definition	L	H	L	L	L	L
Assessment of exposure	L	L	L	L	L	L
Assessment of outcome	L	H	L	H	H	L
Reliability of exposure estimates	U	U	U	U	U	U
Reliability of outcome estimates	U	U	L	U	U	L
Confounder assessment	H	U	H	H	U	H
Sampling bias	H	H	H	H	H	H
Research specific bias	H	H	H	H	L	L
Exclusion bias	H	U	U	U	U	U
Attrition bias	NA	NA	NA	NA	NA	NA
Funding	U	U	U	U	U	U
Conflict of interest	U	U	U	U	U	U
Blinding	U	U	U	U	U	U
Selective reporting of results	L	U	L	L	L	L

Risk of bias domains	D'Mello et al., 2011	Fadel et al., 2014	Gupta et al., 2014	Guven Polat et al., 2012	Hilgers et al., 2006	Loyola et al., 2010
Exposure definition	L	L	L	L	L	L
Assessment of exposure	H	L	L	U	H	L
Assessment of outcome	H	L	L	H	H	L
Reliability of exposure estimates	U	U	U	U	L	U
Reliability of outcome estimates	U	L	U	U	L	L
Confounder assessment	H	H	H	H	H	H
Sampling bias	H	H	U	H	H	H
Research specific bias	H	L	L	H	H	H
Exclusion bias	U	U	U	U	U	L
Attrition bias	NA	L	NA	U	NA	L
Funding	U	U	U	U	U	U
Conflict of interest	U	L	L	U	U	U
Blinding	U	U	U	U	L	L
Selective reporting of results	L	L	L	L	L	H

Risk of bias domains	Modeer et al., 2010	Pinto et al., 2007	Reifsnider et al., 2004	Sancez et al., 2010	Scheutz et al., 2007	Tang et al., 2013
Exposure definition	L	H	H	L	L	L
Assessment of exposure	L	H	H	L	L	L
Assessment of outcome	H	H	H	L	L	H
Reliability of exposure estimates	U	U	U	L	U	U
Reliability of outcome estimates	U	H	U	L	L	U
Confounder assessment	H	H	H	H	H	H
Sampling bias	H	H	H	H	U	H
Research specific bias	H	H	H	H	H	H
Exclusion bias	U	U	U	U	U	U
Attrition bias	U	NA	NA	L	H	NA
Funding	H	U	U	L	U	L
Conflict of interest	U	U	U	L	U	U
Blinding	U	L	U	L	U	U
Selective reporting of results	L	L	U	L	L	L

Risk of bias domains	Tong et al., 2014
Exposure definition	L
Assessment of exposure	L
Assessment of outcome	L
Reliability of exposure estimates	U
Reliability of outcome estimates	L
Confounder assessment	H
Sampling bias	H
Research specific bias	L
Exclusion bias	U
Attrition bias	H
Funding	U
Conflict of interest	L
Blinding	U
Selective reporting of results	L

Appendix 7. Principal Invitation Letter

Date

Full name of principal

School name

School address

School postcode

Dear Mr/Ms “principal’s full name”,

Title of Project: Anthropometric Assessments and Oral Health in Children in Plymouth

We are writing to kindly ask your school’s support/participation in a research study about children’s body weight and dental health, which is being conducted by the University of Plymouth.

The situation in Plymouth with regard to both children’s excess body weight and their oral health is of concern. In addition, it is clear that two health issues of significant public health impact have similar patterns of distribution in Plymouth. This raises the hypothesis that there may be common causal factors/behaviour which could be the target for an intervention to improve the health status of Plymouth children.

In its effort to contribute to the battle against health inequalities in Plymouth, the University of Plymouth, with the support of Public Health England and the Local Authority, is conducting a study among 4-5 year old children. The purpose of the study is to examine whether, amongst children in Plymouth there are high levels of dental caries, high levels of excess body weight, and whether the two variables are associated. If they are, then public health efforts to moderate the common risk factor (diet) could be targeted to the children in most need. Please note that this study is different from the National Child Measurement Program (NCMP), during which the height and weight of children in reception year and year 6 are measured every year.

Our study population is 4 to 5 year old children attending state-maintained infant and primary schools in the Local Authority. The children that will participate in the study will have their teeth examined at school (by a trained dentist who will use different gloves and mirrors for each child) and will have their growth measurements (weight, height, triceps skinfold thickness, waist and hip circumference) taken in light clothing by a trained researcher. The whole procedure will last approximately 10-15 minutes and at the end of the examination, children will be given a participation certificate and a sticker. All data will be treated with strict confidentiality and no individual child or school will be identifiable during the reporting of the results.

We will also ask the school for some information about the children that will participate in the study, including name, gender, postcode, ethnicity and date of birth. Permission for this data sharing will be included in the parental invitation letter. In addition, we will

ask parents to complete a simple questionnaire regarding their children's oral hygiene and dietary habits.

Following the collection of data, we will send parents/guardians a 'thank you' letter and some leaflets/booklets on dental health and healthy eating. If a child's dental condition requires further investigation (for example, he/she is suffering from severe decay or has abscesses), we will arrange a free appointment at the Dental Education Facility of Plymouth University. All data will be treated with strict confidentiality and no individual child or school will be identifiable during the reporting of the results.

We would also like to inform you that the study has been reviewed and approved by the Faculty of Health and Human Sciences Research Ethics Committee-Plymouth University and all researchers involved have received DBS/CRB clearance.

If you agree to participate in the study, the school will be kindly asked to support the programme by:

- Providing class lists and routine data about the children whose parents have consented to take part in the study
- Sending letters to parents/carers providing information about the study and asking them to provide their consent for their child's participation in the study-the research team will provide the letters to be given to pupils to take home to their parents/guardians
- Sending a questionnaire to the parents of the children who will take part in the study-the questionnaire will again be provided by the research team
- Collecting the names of children who were not given consent to participate in the study
- Setting a date when the measurements could take place at school
- Identifying a room or area where the measurements can be taken privately; it would be appreciated if a washing basin is within or in a close distance to the room
- Coordinating with staff to bring children to and from the measurement area

Overall, the findings of this study will help us to gain a good understanding of children's oral health and growth in Plymouth, so that the best appropriate programmes can be developed to help them and their families. Your school's participation is of great importance and we would greatly appreciate your support and cooperation over the conduct of the study.

A researcher will contact you soon to discuss the programme further and provide answers to any queries you may have. Please find attached for your consideration, a support letter from Plymouth Council. In the meantime, should you need any further information, please contact the principal investigator:

Martha Paisi
Plymouth University,
Peninsula Schools of Medicine and Dentistry,
C206, Portland Square,
Drake Circus, Plymouth
PL4 8AA.
Telephone: 01752 586823
Email: martha.paisi@plymouth.ac.uk

We thank you in advance.

Yours sincerely

.....

Prof. Elizabeth Kay

Foundation Dean,
Peninsula Dental School,
Plymouth University.

.....

Dr. Rob Witton

Director of social engagement & community-based dentistry,
Peninsula Schools of Medicine and Dentistry,
Plymouth University.

04 January 2015

Title of Project: Anthropometric Assessments and Oral Health in Children in Plymouth

Dear Parent/Guardian,

Your child is invited to take part in a research study about children's growth and dental health, which is being conducted by the University of Plymouth. We selected your child as a possible participant because she/he is in the age range we need for our study. We kindly ask you to read the information below and ask any questions you may have before consenting to your child's participation in our study. This study is different from the National Child Measurement Programme (NCMP), during which the height and weight of children in reception year and Year 6 are measured every year.

The study

In its effort to improve the overall health of children in Plymouth, the University of Plymouth is conducting a study among 4-5 year old children in the reception year. In particular, we are looking at how children's growth and dental health are related.

The study will take place in the school on "day and date". The children taking part will have their teeth examined by a dentist (who will use different gloves and mirrors for each child) and some growth measurements taken by a trained researcher (weight, height, waist and hip circumference and body fat). The growth measurements will be taken with children in light clothing. The whole procedure will last about 10 minutes and at the end of the examination, your child will receive a participation certificate and a sticker. If the school agrees, we would be happy to see you at the school if you would like to be present at the day of the examination.

If your child takes part in the study, we will ask the school to give us some data about your child including, name, gender, ethnicity and date of birth. We will also ask you to complete a simple questionnaire about the eating and oral health habits of your child (for example tooth brushing).

Does my child have to participate?

The participation in the study is completely voluntary. It is up to you to decide if you would like your child to participate in the study and this will not affect your child's care or education in any way. If you allow your child to participate in the study, you are still entitled to withdraw him/her at any stage without the need to give any explanations and without any penalty. Furthermore, your child may also withdraw from the study at anytime.

Are there any possible benefits of my child taking part in the study?

After the measurements are taken, we will send you a 'thank you' letter as well as leaflets/booklets on dental health and healthy eating. If your child has a dental condition which requires further investigation, we will offer a free appointment at the Dental Education Facility of Plymouth University (Derriford or Devonport). Overall, the findings of this study will help us to gain a good understanding of children's dental health and growth in Plymouth, so that the best appropriate programs can be developed to help them and their families.

Are there any possible risks of my child participating in the study?

There is no risk of any harm involved in this study. The growth measurements may perhaps make your child feel a bit shy, however, all measurements will be taken sensitively by the research staff and appropriate support will be given if any anxieties arise. Furthermore, if a child feels uncomfortable on the day of the examination, he/she will be able to pull out from the study even if their parent/guardian consented to their participation.

Privacy and Confidentiality

Before the measurements, we will ask the school to locate a private room where the measurements could take place; this will be approved by our research team. On the examination day, only the researchers that will be involved in the study will be able to see or hear the individual children's results.

All information that we will collect about your child will be treated with strict confidentiality and will not be given to the school or other parents/children. Furthermore, at the beginning of the study we will give your child a study number which will make him/her completely anonymous to everyone except the research team. The data will be kept securely in a computer file at the University of Plymouth and only the research staff will have access to it. Once the study has finished, the results of all children who took part in the study will be analysed together and published in a scientific journal. Only anonymous data will be used and no names (of children or schools) will appear in any reports, presentations or publications.

If we have any concerns about your child's results, we will post information directly to your home address in an envelope which will be clearly marked "Private and Confidential".

Who has reviewed the study?

This study has been reviewed and approved by the Faculty of Health and Human Sciences Research Ethics Committee-Plymouth University whose aim is to protect the participants' rights and interests. In addition, all researchers that will be involved in the measurements have received DBS/CRB clearance.

What if I have a concern about the study?

If you have any concerns about any part of this study, you can contact Professor Elizabeth Kay (Foundation Dean of Peninsula Dental School, Plymouth University) on 01752 586803 or elizabeth.kay@plymouth.ac.uk. If, after, talking to Professor Kay you still have concerns, you can contact Ms. Sarah Jones (Administrator of the Faculty Human Ethics Committee, Plymouth University) on 01752 585339 or sarah.c.jones@plymouth.ac.uk.

Further information

If you have any questions about the study or you would like further information, you can contact the principal investigator:

Martha Paisi
Plymouth University,
Peninsula Schools of Medicine and Dentistry,
C206, Portland Square,
Drake Circus, Plymouth, PL4 8AA.
Telephone: 01752 586823
Email: martha.paisi@plymouth.ac.uk

Thank you for reading this information. Please read the enclosed consent form and if you are happy for your child to taking part in the study, please sign and return it to the school.

Yours sincerely,

.....

.....

Prof. Elizabeth Kay

Dr. Rob Witton

Foundation dean,
Peninsula Dental School,
Plymouth University.

Director of social engagement & community-based dentistry,
Peninsula Schools of Medicine and Dentistry,
Plymouth University

Appendix 9. Consent Form

Title of Project: Anthropometric Assessments and Oral Health in Children in Plymouth

Child's name (full name): _____ Class _____

House address: _____ Postcode _____

Please put your initials in all boxes if you agree

I confirm that I have read and understand the information sheet dated.....for the above study. I have had the opportunity to ask questions and understand what is involved.

I understand that my child's participation is voluntary and that I can withdraw him/her from the study at any time without giving any explanations, and without their care or education being affected.

I understand that the information held and maintained by Plymouth University could be used to help contact me or provide information about my child's health status.

I understand that I can ask for information regarding my child's results at anytime.

I agree to my child participating in this study.

(Printed name of parent/guardian)
block capitals

Signature

Date

Relationship to participant: _____

This project has been reviewed and approved by the Faculty of Health and Human Sciences Research Ethics Committee-Plymouth University

Participant identification Number for this study:

Appendix 10. Parent/Guardian Questionnaire

Dear Parent/Guardian,

As part of the study “*Anthropometric Assessments and Oral health in Children in Plymouth*”, we would like to know more about the eating and oral health habits of children. Please could you complete this questionnaire and return it to the school within one week, in the brown envelope provided.

Your answers will remain confidential and we will group the anonymised results so no one can be identified.

Please answer the questions that follow by TICKING the box that is relevant to you.

(A) This part is about you (parent/guardian)

1) How old are you?

<20 ☐

20-29 ☐

30-39 ☐

40-49 ☐

50 + ☐

2) How are you related to the child who you kindly agreed could join this study?

Mother ☐

Father ☐

Grandmother ☐

Grandfather ☐

Other ☐ (please give details.....)

3) What is the highest level of education you have completed?

- Primary school ☐
- Secondary school ☐
- Technical school/
College ☐
- University ☐
- Other ☐ (please give
details.....)

4) What category best describes your household's total income over the last 12 months?

- Up to £5,199 ☐
- £5,200 to £25,599 ☐
- £26,000 to £36,399 ☐
- £36,400 to £51,999 ☐
- £52,000 and above ☐
- Prefer not to answer ☐

B) This part is about your child

5) How often are your child's teeth brushed/cleaned?

- Never ☐
- Less than once a day ☐
- Once a day ☐
- Twice a day ☐
- Three times a day or more ☐

6) How old was your child when they first started having their teeth cleaned?

Under 1 year ☐

1 – 2 years ☐

2 – 3 years ☐

3 years or over ☐

Cannot remember ☐

Teeth are not cleaned ☐

7) Does an adult stay with your child while they brush?

Yes ☐ No ☐

8) Has your child visited a dentist in the last 12 months?

Yes ☐ No ☐

If the answer to question was YES, did your child attend the dentist because:

you knew a routine check up was due ☐

the dentist sent you a reminder for a check ☐

the school dentist sent a note home suggesting a check up ☐

they had toothache or some other problem ☐

9) On average in the last 7 days, how many times per day ***in between meals*** did your child have each of the food item/beverages listed below?

Please tick one box in each row. If your child did not eat this food, or drink this beverage in between meals during the past week, please tick “never”.

Type of food or drink	Never	Less than once a day	1 time/day	2 times/day	3 times or more/day
Sugar confectionary (sweets, toffees, chewing gum)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chocolate confectionary (any type of chocolate bar)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Biscuits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cakes, pastries and fruit pies (including doughnuts)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Puddings (including rice, sponge pudding and jelly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Yoghurt and other dairy desserts (such as mousse)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Breakfast cereals	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sugars, syrups, sweet spreads (including sugar added to the tea or breakfast cereals, jam, honey)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Type of food or drink	Never	Less than once a day	1 time/day	2 times/day	3 times or more/day
Fruit (fresh and dried)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fruit juice (including freshly squeezed and 100% single or mixed fruit juices/smoothies)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fruit drinks (such as squash, fruit shoot, Capri Sun, flavored teas)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sugared/regular soft drinks (such as coca-cola, sprite)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sugared milk-based beverages (including milk shake, hot chocolate)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Thank you very much for your time.

Appendix 11. Thank you letter to parents/guardians of children with healthy weight and no caries

Private and confidential

Full name of parent/carer

Address

Postcode

Date: _____

Dear Parent/Guardian of “Student’s first name”,

Re: Anthropometric Assessments and Oral Health in Children in Plymouth

We would first like to thank you for your child’s participation in the study looking at growth and dental health in children in Plymouth. The findings of this study will help us develop the best appropriate programs to improve the overall health of children in Plymouth.

Please find enclosed two leaflets and a poster on dental health and healthy eating, which have been sent to all parents/guardians of the children participating in the study. We hope the information is useful to you.

Thank you again for consenting to the participation of your child in our study.

Yours sincerely

.....

Elizabeth Kay

Foundation Dean,
Peninsula Dental School,
Plymouth University.

.....

Martha Paisi

Principal Investigator,
Peninsula Schools of Medicine and Dentistry,
Plymouth University.

Appendix 12. Letter to parents/guardians of children with caries

Private and confidential

Date: _____

Dear Parent/Guardian,

Re: Anthropometric Assessments and Oral Health in Children in Plymouth

We would first like to thank you for your child's participation in the study looking at growth and dental health in children in Plymouth. The findings of this study will help us develop the best appropriate programs to improve the overall health of children in Plymouth.

The results of your child suggest that his/her teeth may benefit from attending for dental care. For this reason, we would like to offer an appointment at the Dental Education Facility of Plymouth University, Peninsula Dental School. There will be no charge for this. To make an appointment and for more details, please contact the appointment team on 0345 155 8109 (term time only).

Please note that we treat your child's results with strict confidentiality and we have not shared them with your child, other children or the school.

Enclosed are two leaflets and a poster on dental health and healthy eating, which have been sent to all parents/guardians of the children participating in the study. A leaflet and a poster on the Dental Education Facility are also enclosed.

Thank you again for consenting to your child's participation in this study.

Yours sincerely

.....

Elizabeth Kay

Foundation Dean,
Peninsula Dental School,
Plymouth University.

.....

Martha Paisi

Principal Investigator,
Peninsula Schools of Medicine and Dentistry,
Plymouth University.

Appendix 13. Ethical Approval (PDF)



16th June 2014

CONFIDENTIAL

Martha Paisi
Peninsula Schools of Medicine and Dentistry
C206 Portland Square
Drakes Circus
Plymouth
Devon
PL4 8AA

Dear Martha

Application for Approval by Faculty Research Ethics Committee

Reference Number: 13/14-240

Application Title: Anthropometric Assessments and Oral Health in Children in Plymouth

I am pleased to inform you that the Committee has granted approval to you to conduct this research.

Please note that this approval is for three years, after which you will be required to seek extension of existing approval.

Please note that should any MAJOR changes to your research design occur which effect the ethics of procedures involved you must inform the Committee. Please contact Sarah Jones (email sarah.c.jones@plymouth.ac.uk).

Yours sincerely

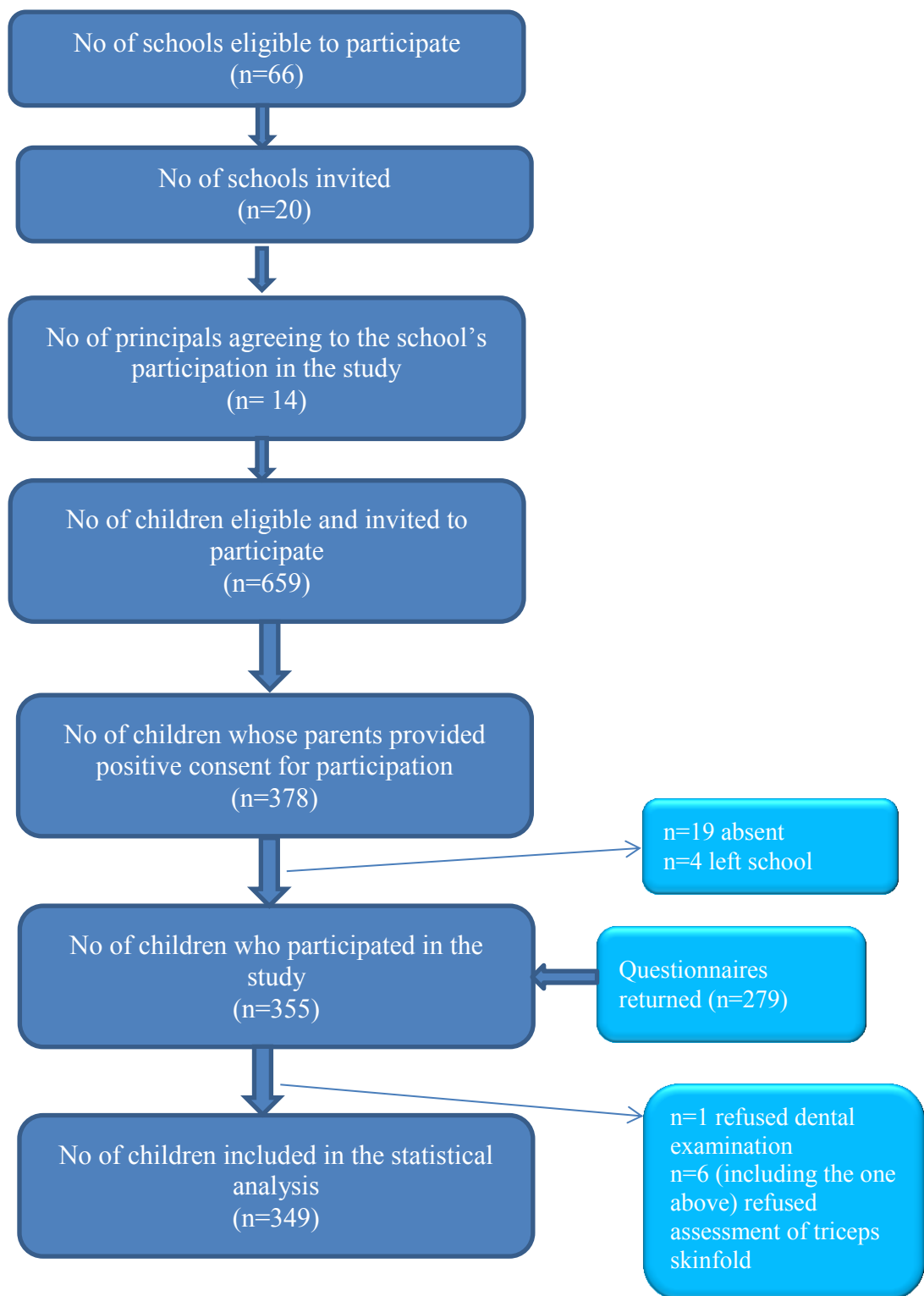
Professor Michael Sheppard, PhD, AcSS,
Chair, Research Ethics Committee -
Faculty of Health & Human Sciences and
Peninsula Schools of Medicine & Dentistry

Faculty of Health & Human Sciences
Plymouth University
Drake Circus
Plymouth PL4 8AA

T +44 (0)1752 585339
F +44 (0)1752 585328
E sarah.c.jones@plymouth.ac.uk
W www.plymouth.ac.uk

Professor Michael Sheppard
CQSW BSc MA PhD AcSS
Chair, Faculty Research Ethics
Committee

Appendix 14. Recruitment procedure for school survey



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